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DESIGN, TEST, AND ACCEPTANCE CRITERIA FOR ARMY HELICOPTER TRANSPARENT ENCLOSURES

Harold C. James, et al

Goodyear Aerospace Corporation

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By

Harold C. James
A. O. Ingelse
Richard Huyett

May 1973

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

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The high cost of replacement of helicopter transparencies is of serious concern to the U.S. Army. A recent study of 412 windshield replacement actions revealed that the average replacement occurred every 307 flying hours.

As a result of this concern, the Army contracted for a systematic study of the design, test, and acceptance criteria for helicopter transparent structures to improve the overall reliability and maintainability of these transparencies.

Data were collected and analyzed; existing criteria were evaluated for effectiveness and relative importance for different classes of helicopters; and recommendations have been made for detailed design objectives, testing, and acceptance criteria.

The data collection on which these recommendations were based include both objective and subjective data. Extensive interviews with operational and maintenance personnel provide a broad "real-world" basis for evaluation of the statistical tabulations of transparency replacement actions.

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Door and Passenger Window						
Transparent Material Properties						
Notch Sensitivity						
Crazing Susceptibility						
Crack Propagation						
Monolithic Windshield Glazings						
Cast Acrylic						
Stretched Acrylic						
Laminated Windshield Materials						
Polyvinyl Butyral Sheet Interlayer						
Flexible Interlayers						
Polycarbonate Plastic Sheet						
Ally Diglycol Carbonate						
Abrasion Resistance Materials						
Fracture Resistance Materials						
Glass/Plastic Composites						
Laminated Glass						
Laminated Glass/Plastic						
Advanced Glass/Plastic Transparent Armor						
Radar Cross Section Reduction Coatings						
Reflectance Reduction						
P-Static Phenomenon						
Dielectric Failure						
Polarization						
Delaminated Transparencies						

DEPARTMENT OF THE ARMY
U. S. ARMY AIR MOBILITY RESEARCH & DEVELOPMENT LABORATORY
EUSTIS DIRECTORATE
FORT EUSTIS, VIRGINIA 23604

This report was prepared by the Goodyear Aerospace Corporation under the terms of Contract DAAJ02-72-C-0074. It presents the results of an effort to develop improved design, test, and acceptance criteria for helicopter transparent structures that will meet the mission requirements of present and future Army helicopters.

The results of this investigation indicate that the properties most commonly used in design have been widely tested and test values documented for all currently used transparency materials. However, the number of tests of any specific material, material property, and test condition are limited, and the test results are most commonly reported only as "average values" or as "typical properties". As a result, there are no data that can be construed as design values comparable to the values for the most commonly used metals.

This report has been reviewed by the Directorate and is considered to be technically sound.

The technical monitor for this contract was Major Andrew E. Gilewicz of the Military Operations Technology Division of this Directorate.

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Task 1F162205A11904
Contract DAAJ02-72-C-0074
USAAMRDL Technical Report 73-19
May 1973

DESIGN, TEST, AND ACCEPTANCE CRITERIA FOR ARMY HELICOPTER TRANSPARENT ENCLOSURES

Final Report

By

Harold C. James
A.O. Ingelse
Richard Huyett

Prepared By

Goodyear Aerospace Corporation
Arizona Division, Litchfield Park, Arizona

for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

ABSTRACT

The high cost of replacement of helicopter transparencies is of serious concern to the U.S. Army. A recent study of 412 windshield replacement actions revealed that the average replacement occurred every 307 flying hours.

As a result of this concern, the Army contracted for a systematic study of the design, test, and acceptance criteria for helicopter transparent structures in order to improve the overall reliability and maintainability of these transparencies.

Data was collected and analyzed; existing criteria were evaluated for effectiveness and relative importance for different classes of helicopters; and recommendations have been made for detailed design objectives, testing, and acceptance criteria.

The data collection on which these recommendations were based includes both objective and subjective data. Extensive interviews with operational and maintenance personnel provide a broad "real world" basis for evaluation of the statistical tabulations of transparency replacement actions.

FOREWORD

Work on the program reported herein was authorized by Contract DAAJ02-72-C-0074 (Task 1F162205A11904) issued by the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia.

The work was performed by Goodyear Aerospace Corporation, Litchfield Park, Arizona.

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INTRODUCTION

THE PROBLEM

The frequency of replacement of transparent structures in helicopters has become of growing concern to the U. S. Army. As a result of this growing concern, it was decided by the Eustis Directorate of the United States Army Air Mobility Research and Development Laboratory that a fresh look at the design, testing, and acceptance criteria for transparent helicopter structures was in order. The improvement of the overall reliability and maintainability for the helicopter transparencies was the primary objective of the study program.

BACKGROUND

Several reports have been generated that disclose considerable objective data showing the failure mode of helicopter transparencies. Among these reports was the Special Study - UH-1D Windshield Replacement Repair, dated 12 October 1970, by the Systems Engineering Directorate, U. S. Army Aviation Systems Command, St. Louis, Missouri, and the Value Engineering Study 664999 by the U. S. Army Aeronautical Depot Maintenance Center, Corpus Christi, Texas, on 17 April 1969.

APPROACH

The approach to the problem initially consisted of the data collection effort.

This data was collected and assembled from Goodyear Aerospace Corporation's engineering files, and from prime helicopter manufacturers and military installations.

The data collected and assembled consisted of military specifications, engineering designs, testing requirements (both qualification and acceptance testing), failure mode analysis from computer banks, and manually retrieved failure mode data. Another type of data collected was the subjective data obtained in personal interviews with experienced pilots, maintenance personnel, and representatives of various levels of management.

This interview data was obtained from a significant number of personnel and from a representative cross section of pilots and maintenance personnel from among Army, Navy, Air Force, Marine Corps, and civilian ranks.

This tabulated data thus becomes a set of guidelines to establish the design, acceptance, and test criteria for helicopter transparencies.

This tabulated data, together with pertinent comments, is included as Appendix I. A list of military and commercial specifications that were collected and analyzed is included as Appendix II. Appendix III is a model specification which has been generated using the tabulated data as a guide. The model specification is arranged in a manner such that the helicopter transparencies may be individually defined. The interview data were tabulated and the table on page 19 is a compilation of the problem areas as expressed by 82 using personnel. This subjective data reinforces and clarifies the various other types of failure mode data which has been produced.

MAINTENANCE RECORDS

The reporting procedures utilized by the Army have resulted in voluminous records at the Army Aviation Systems Command in St. Louis (AVSCOM). During the study program, RAMMIT (Reliability and Maintainability Management Improvement Techniques) Maintenance Action files were used. A computer run showing a maintenance action summary for the AH-1G helicopter was immediately available. A special extract of available maintenance actions relating to helicopter transparencies was supplied for analysis.

During the analysis of the computer data, there were several line items that were discarded. The noun descriptor in the "failure code-description list" did not coincide with the Federal Stock Number (FSN). This may be illustrated by the example of an FSN for a helicopter door assembly being recorded with a corresponding failure code showing "broken, " whereas in reality the hinge was broken and the associated transparency was intact.

DISCUSSION

MODEL DESIGNATION AND MISSION

General

The Army today has five groupings of helicopters by model designation: (1) observation, (2) trainer, (3) utility, (4) cargo, (5) attack.

Observation Helicopter

The primary tactical mission of the observation helicopter is visual observations, target acquisition, reconnaissance, command control, and armed scout missions.

Utility Helicopter

This type of helicopter provides tactical mobility for Army combat troops and supplies. It performs aeromedical evacuation and command and control roles. Some models of the utility helicopter are employed as weapons helicopter.

Cargo Helicopter

The cargo helicopter provides air mobility to military forces in the field by the transport of personnel, weapons, and cargo in both combat assault support and logistical support roles. This type of helicopter also provides aeromedical evacuation and downed aircraft recovery capabilities.

Attack Helicopter

The mission of the attack helicopter is one of direct aerial fire support, escort, reconnaissance, and security.

TRANSPARENCY FUNCTION AND LOCATION

Transparencies on helicopters have two basic functions:

1. Transmit visible light
2. Protect interior from exterior environment.

These functions are obviously somewhat contradictory in that the visible light being transmitted is a part of the exterior environment. The degree to which these functions must be provided by the transparency is controlled by the mission of the helicopter and the location on the helicopter.

Helicopter transparencies are generally identified in one of the following categories:

1. Windshield
2. Chin or nose bubble
3. Eyebrow window or skylight
4. Door and passenger window.

These four categories identify the transparency by location. The design criteria for the transparencies will be established by these categories.

The existing configuration of several observation-type helicopter transparencies assumes the shape of a notched-out sphere. This transparency has been fabricated as a single piece, or pieced together, utilizing four to six independent transparencies connected with splice strips and doublers. This type of configuration will be considered as a windshield for purposes of establishing design criteria.

The windshield is the most critical of the categories. It has the most critical requirements for undistorted optical transmission because the visual observations are normally forward through the windshield area. The windshield is also subject to the most severe external environment because the direct airflow with the various contaminants impinges most directly on this area.

TRANSPARENT MATERIAL PROPERTIES

GENERAL

MIL-HDBK-17, Plastics for Flight Vehicles, Part II - Transparent Glazing Materials, was prepared by the National Bureau of Standards and approved in August 1961. This handbook provides a wealth of information for the selection of materials for transparencies in aircraft.

This handbook is currently in the process of being revised,and the revised edition will include data recently developed in new transparent materials. This revised handbook is scheduled for publication in 1973.

Table I is a summary of the advantages and disadvantages of transparent materials that are currently utilized in helicopter transparencies.

Table II is a compilation of the properties of the basic transparent materials currently utilized in helicopter transparencies.

The data presented is primarily data obtained from the manufacturer of the transparent raw material. Additional data is included which has been developed by Goodyear Aerospace Corporation in the preparation of Technical Report AFML-TR-72-117, Design Criteria, Transparent Polycarbonate Sheet. This data should be considered as typical test properties.

Government specifications do not specify the maximum design allowable strength values for plastic transparent materials. The actual values are at the discretion of the design engineer, and are of necessity only a small percentage of the material ultimate strength.

Two additional characteristics of transparent plastic materials that must be considered for an effective design are the notch sensitivity and crazing susceptibility. These two characteristics are discussed in later paragraphs under these headings.

MECHANICAL PROPERTIES

The mechanical properties of applicable transparent materials are included in Table II. The tensile properties shown for the plastic materials are the short-term tensile properties, which are the usual basis for comparing strength properties of these materials.

TABLE I. SUMMARY OF ADVANTAGES AND DISADVANTAGES OF TRANSPARENT MATERIALS CURRENTLY UTILIZED IN HELICOPTER TRANSPARENCIES

Materials Identification	Typical Uses	Advantages	Disadvantages
Soda-Lime Glass (MIL-G-25667)	Face sheets in laminated assemblies - armor, bird impact, and anti-icing windshields.	Excellent high temperature resistance in excess of 500°F. Practically impervious to chemical attack and stress-solvent crazing. Excellent abrasion resistance. Excellent optical properties. No degradation in properties with aging.	Low strength-to-weight ratio Poor thermal shock properties. Fails catastrophically without warning. Contour forming limitations.
Chemically Strengthened Glass (MIL-G-25667, Type V)	Face sheets in laminated assemblies with themselves and stretched acrylic.	Same as soda-lime glass except greatly improved strength-to-weight ratio.	Subject to stone damage and breakage on edge impact. Break pattern may cause visibility problems.
Cast Acrylic (MIL-P-5425)	Monolithic windows in nonpressurized aircraft.	Can be formed to most contours. Good optical properties for intended use.	Very poor resistance to stress-solvent crazing. Poor crack propagation resistance. Poor abrasion resistance.

TABLE I - Continued

Materials Identification	Typical Uses	Advantages	Disadvantages
Modified Cast Acrylic (MIL-P-8184)	Monolithic and laminated assemblies. Thermal barrier sheets in laminated acrylic assemblies.	Can be formed to most contours. Good optical quality, except at high angle of incidence. Good thermal barrier properties.	Poor resistance to stress-solvent crazing. Poor crack propagation resistance. Poor abrasion resistance.
Stretched Acrylic (MIL-P-25690)	Monolithic and laminated assemblies. Load bearing in composite laminated assemblies.	Excellent long-term aging properties. Good stress-solvent crazing resistance. Formability to moderate contours. More versatile than as-cast acrylic, but limited to extent of forming elongation. Good strength-to-weight ratio. Surface can be restored during service. Good optical properties, except at high angles of incidence.	Shrinks back at high temperature. Poor abrasion resistance. Subject to creep at elevated temperature.

TABLE I - Continued

Materials Identification	Typical Uses	Advantages	Disadvantages
Polyesters (MIL-P-8257)	Outer nonload bearing face sheets in laminated assemblies.	Good abrasion resistance properties (poly-allyl types). Good elevated temperature properties (alkyd types). Good solvent resistance.	Very poor notch and impact properties. Contour forming limitations. Very brittle at low temperatures. Low strength at high temperatures. Poor fatigue properties. Poor thermal shock properties.
Polycarbonates (MIL-P-83310)	Monolithic structural panes and laminated assemblies when increased impact resistance and temperature resistance are critical.	Excellent toughness and crack propagation resistance. Good strength-to-weight ratio. Good thermal properties to 300°F. Self-extinguishing. Good thermal shock properties.	Very poor solvent resistance to common alcohols and aliphatics. Very poor abrasion resistance.

TABLE II. PROPERTIES OF HELICOPTER TRANSPARENCY MATERIALS

Property	ASTM Method	FTSM 406 Method	Units	MIL-P 5425 Heat Resistant Acrylic	MIL-P-8184 Modified Acrylic	MIL-P-25690 Stretched Acrylic	MIL-P-83310 Polycarbonate	MIL-P-8256 Polyester Base	L-P-516 G-3 Polyester	MIL-G-25667 Glass Type V	Remarks
Tensile Strength	D-638	1011 0.05 in./min	Psi × 10^3	10.5	11.0	11.0	8.0-9.5	8.0-10.0	5.0-6.0	30.0	
Tensile Modulus	D-638	-	Psi × 10^5	4.5	4.5	4.5	3.2-3.5	-	3.0	107.4	
Compressive Strength	D-695	-	Psi × 10^3	16.0	19.0	17.0	12.5	30.0	22.8	-	
Compressive Modulus	D-695	-	Psi × 10^5	4.5	4.5	5.0	2.4	-	2.3	-	
Flexural Strength	-	-	Psi × 10^3	16.0	16.0	15.0	12.2-12.7	12.0-20.0	8-10	25.0	
Flexural Modulus	D-790	-	Psi × 10^5	4.5	4.5	5.0	3.2-3.5	5.0-5.5	2.5-3.3	10.0-11.5 × 10^{-6}	
Shear Strength	D-732	-	Psi × 10^3	9.0	9.5	9.0		5.4	-	-	
Izod Impact (Notched)	D-256	-	Ft lbs/in. notch	0.4	0.4	-	14-17.5*	0.20	0.3-0.4	N/A	
Izod Impact (Unnotched)	-	-	Ft lbs/in. width	-	-	9-10*	60*	1.25	2-3	N/A	
Rockwell Hardness	D-785	-	-	M93	M93	M96	M75	M100-115	M95-100	D66	One hundred Kg load. Brale penetrator
Coefficient of Thermal Expansion	D-696	-	in./in./°F × 10^{-5}	3.6	3.5	3.5	3.75	5.5-7.0	6 × 10^{-5}	40-60 × 10^{-7}	
Specific Gravity	D-792	-	-	1.19	1.19	1.19	1.2	1.20-1.26	1.31	2.51	
Thermal Conductivity	-	-	BTU/in./h/ft²/°F	1.3	1.2	1.2	1.34	-	1.45	6.67	
Specific Heat	-	-	BTU/lb/°F	0.35	0.35	0.35	0.29	-	0.55	0.192	
Heat Deflection											
Temperature at 264 psi	D-648	-	°F	205	212	210	265-290	150-176	-	>500	
Temperature at 66 psi	D-648	-	°F	225	225	-	289	-	-	N/A	
Flammability	D-635	-	in./min	1.1	0.5	0.5	Self-extinguishing	1.0-2.0△	0.3	Nonburning	1/8-inch sheet: △0.060 to 0.75-inch thickness, respectively
Refractive Index	D-542	-	Nd	1.49	1.50	1.50	1.586	1.55	1.50	1.506	
Transmittance, Luminous	D-1003	3022	Percent	91	91	91	85-91	70, 89△	89-91	84.8-89.0	Based on 1/4-inch-thick material
Haze	D-1003	3022	Percent	1	1	<4	<1	<3	1-2	<1	Based on 1/4-inch-thick material
K-Value (Crack Propagation Resistance)	-	-	10^3 lbs/in.$^{3/2}$	1.2	1.3	-2.6	3.0	-	-	N/A	3/8-inch material crosshead rate: 0.02 in./min at 76° F

*After thermal processing.

The mechanical properties over a wide temperature range, varying loading rates, weathering effects, and long-time loading are documented in Part II of MIL-HDBK-17.

NOTCH SENSITIVITY

Many of the materials used in plastic transparencies are very sensitive to stress concentrations and have little resistance to crack propagation, so that once a crack has started, little energy is needed to cause complete failure. The notch sensitivity of acrylic is greatly decreased, and the resistance to crack propagation greatly improved, by stretching. Some measure of the notch sensitivity may be determined by means of flexural and impact tests with controlled notches on the tension side of the specimens.

The commonly accepted method of evaluating the crack propagation resistance is the determination of the K-value.

The procedure for determining the K-value was developed at the Naval Research Laboratory and is described in reports authored by J. A. Kies and H. L. Smith.[a, b, c]

The method of determining the K-value of stretched acrylic is documented in MIL-P-25690, and minimum values for quality determinations are included.

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[a] Kies, J. A., and Smith, H. L.: "Aircraft Glazing Materials. Resistance to Crack Propagation," Naval Research Laboratory Memorandum Report 372 (1954).

[b] Kies, J. A., and Smith, H. L.: "Toughness Testing of Hot Stretched Acrylics," Materials Laboratory, Directorate of Research, Wright Air Development Center, Air Research and Development Command, Summary of Joint AIA-WADC Transparent Materials Conference, Dayton, Ohio (March 1955).

[c] Smith, H. L., and Kies, J. A.: "Engineering Applicability of Toughness Values," in "Transparent Materials for Aircraft Enclosures, WADC-University of Dayton Joint Conference," by R. E. Wittman, Wright Air Development Center Technical Report 57-421, pp 7-19 (October 1957).

CRAZING SUSCEPTIBILITY

Crazing may be defined as very fine cracks. These fine cracks are approximately perpendicular to the surface, are very narrow in width, are usually not over 0.001 inch in depth, and are difficult to discern except by reflection from their surfaces. They appear as bright lines when viewed at varying angles to the incident light.

Crazing may result from many different causes. The two most common causes are residual stress from uneven stretching and cooling involved in forming, and contact with solvents or solvent vapors.

It should be noted that crazing is an irreversible property, although the visible crazing may disappear. Crazing reduces the luminous transmittance and also affects the structural properties of the plastic transparency.

HELICOPTER WINDSHIELDS - GENERAL CONSTRUCTION

MONOLITHIC WINDSHIELD MATERIALS

The materials suitable for use in fabricating monolithic windshield glazings are presently limited to MIL-P-5425 cast acrylic, MIL-P-8184 modified cast acrylic, MIL-P-25690 stretched acrylic, or MIL-P-83310 polycarbonate.

MIL-P-8257 polyester material is not used because of very poor structural properties. The notch sensitivity and impact properties are also poor. The polyester materials have low strength at elevated temperatures and are very brittle at low temperature. Poor thermal shock and fatigue properties have also been noted.

Monolithic glass is subject to catastrophic failure without warning and cannot be utilized for windshield glazings without lamination.

Windshields made from MIL-P-5425 cast acrylic are used in nonpressurized aircraft. The material is formable to most contours and has good optical quality for the intended use, but it has very poor resistance to stress-solvent crazing, poor crack propagation resistance, and poor abrasion resistance.

Windshields made from MIL-P-8184 modified cast acrylic material are used in both pressurized and nonpressurized aircraft. The material is formable to most contours and has good optical quality, except when viewed at high angles of incidence. The resistance to stress-solvent crazing is superior to MIL-P-5425 cast acrylic but greatly inferior to MIL-P-25690 stretched acrylic. The crack propagation resistance and abrasion resistance are poor.

MIL-P-25690 stretched acrylic has significantly improved resistance to crack propagation and stress-solvent crazing. Windshields made from this material are used in both pressurized and nonpressurized aircraft. The stretching operation alters processability to provide greater versatility of contours which can be formed, but results in forming limitations to relatively moderate contours. The material has good stress-solvent crazing resistance and excellent long-term aging properties. Stretched acrylic has a much higher crack propagation resistance and approximately triple the impact strength of cast acrylic material.

Projectiles fired through the material will not cause catastrophic failure even in a pressurized installation. Stretched acrylic yields a higher strength-to-weight ratio than that of laminated cast acrylic. Good optical properties can be obtained except at high angles of incidence.

The material does shrink back at high temperature and is subject to creep at elevated temperature. The abrasion resistance of the material is poor.

Polycarbonate to MIL-P-83310 is a relatively new material which has found use in monolithic windshields. The material has excellent toughness and crack propagation resistance properties. It offers good strength-to-weight ratio and is self-extinguishing. Polycarbonate has good thermal shock properties and retention of physical properties at elevated temperature. It can be formed to most contours; however, attainment of other than free-form contour is difficult without mark-off or other optical impairment.

Polycarbonate has very poor solvent resistance. Common alcohols and aliphatics routinely employed in aircraft operation and maintenance cause severe degradation. The material also has very poor abrasion resistance. The optical quality of polycarbonate is very poor as well. The surface preparation required to obtain acceptable optical quality and specialty coatings required to improve the abrasion and solvent resistance have limited the material's use in aircraft glazings to date.

The physical properties and weathering characteristics of polycarbonate have also not been fully evaluated. There is growing evidence that the impact resistance is adversely affected by environmental conditions which are routinely experienced. This is an area that requires additional study.

LAMINATED WINDSHIELD MATERIALS

Glass-to-Glass Types

Glass-to-glass windshield laminates are used primarily where good vision is of prime importance. Glass used in aircraft must be laminated to retain integrity and prevent catastrophic failure if breakage occurs. Glass-faced windshields offer superior abrasion resistance and are compatible with windshield wiper operation for rain removal. Glass also offers dimensional stability which permits incorporation of electrically conductive coatings for anti-icing/fogging systems.

Laminated glass has a low strength-to-weight ratio and poor thermal shock properties. Chemically strengthened glass is sometimes used to improve these properties. There are restrictive contour-forming limitations for glass aircraft windshields. Such articles are also subject to breakage due to local impact by hard objects (stones, etc.).

The lamination of glass plies is achieved by the use of polyvinyl butyral sheet interlayer or cast-in-place interlayer material.

The complexity of a laminated glass windshield increases many fold when an electrically conductive coating system is incorporated. Typical features and problems encountered with such systems are discussed in the section entitled Glass-to-Plastic Types.

Plastic-to-Plastic Types

Plastic-to-plastic windshield laminates are used primarily to increase impact resistance and to provide a means of incorporating an electrically conductive anti-icing/fogging coating. Such laminates have combined MIL-P-8257 polyester outer face sheets with MIL-P-8184 modified cast acrylic or MIL-P-25690 stretched acrylic load bearing plies. Many other plastic-to-plastic laminates have been fabricated using various combinations of acrylic plies.

The polyester material has been used as an outer nonload bearing face sheet for added abrasion resistance. The abrasion resistance of the polyester is significantly greater than acrylic, yet is far poorer than glass. The material has very poor notch and impact properties and adds limitations to forming contours.

Other properties adversely affecting performance are poor fatigue and thermal shock resistance, low-temperature brittleness, and low strength at high temperature. In service, the polyester face sheets have not added sufficient abrasion resistance to outweigh the negative factors.

Both polyester-faced and all acrylic laminated plastic windshields have been designed for birdproof requirements. Weight of the laminated plastic windshields compares very favorably with either glass or glass/plastic composites. The lamination of the plastic plies is achieved with polyvinyl butyral sheet interlayer or cast-in-place interlayer. The incorporation of an electrically conductive coating for anti-icing/fogging also increases the complexity of a plastic laminated windshield. Typical applications of heated windshields in helicopters together with a discussion of features and problems are presented under the heading that follows.

Glass-to-Plastic Types

Glass-to-plastic windshield laminates represent a very recent attempt to combine the desirable features of both materials in a single glazing for helicopters. Glass is used in the outer face sheet for abrasion resistance, weatherability, and the dimensional stability necessary for an electrically conductive coating.

Chemically strengthened or semitempered glass is most frequently used to increase the strength-to-weight ratio of the laminate. One or more plies of MIL-P-25690 stretched acrylic are used as the structural backing. A cast-in-place or sheet interlayer capable of bonding glass and plastic must accommodate the large differential coefficient of expansion of the two materials. Polyvinyl butyral sheet interlayer is used to bond the stretched acrylic plies. Glass/plastic laminates can be designed for birdproof requirements. This does not appear to be required for helicopter windshields unless flight speeds are significantly increased on future aircraft.

Interlayers

It is necessary that a material be flexible if it is to be used as an interlayer to bond the plies of a laminated windshield. Various formulations of polyvinyl butyral sheet interlayer have been utilized traditionally to join glass-to-glass or plastic-to-plastic plies. Changes in plasticizer type and ratio are incorporated for compatibility and bonding properties for the different substrate materials. Windshields laminated with polyvinyl butyral are limited to approximately 160°F temperature. The material is sensitive to water ingress, and face sheet delamination has occurred. The thermal coefficient of expansion does not match glass, and it becomes stiff at moderately low temperatures. Polyvinyl butyral thus has limitations when it is used to laminate materials such as glass and plastic, which have greatly dissimilar thermal coefficients of expansion.

An interlayer retaining good flexibility and bonding properties is desired to laminate such dissimilar materials. Interlayers in sheet and cast-in-place systems have been used for such purposes. A variety of materials, including polyesters, epoxies, silicones, and polyurethanes have physical properties which may be able to maintain laminate integrity when subjected to thermally induced stress. There are a considerable number of interlayers, most of which are considered company proprietary, used for laminating heated and nonheated windshield composites. Intensive interlayer development efforts have been undertaken by a number of companies. Significant improvements in interlayer technology have already resulted from these programs. Cast-in-place silicone and polyurethane systems are currently favored for most applications. Improvements in physical properties, adhesion to substrates, and processing techniques have combined with advancing windshield design technology to produce better-performing, longer-life products.

DESIGN CONSIDERATIONS BY HELICOPTER MISSION AND TRANSPARENCY LOCATION

GENERAL

The helicopter transparency design considerations have been broken down into the following three major design groups:

1. Primary design considerations
2. Inherent material properties
3. Management design considerations.

The primary design considerations are the properties that will be established through the basic mechanical design effort. These characteristics are established by the mission and performance planned for the helicopter, as well as design arrangement, and can be changed over a given range by the designer.

The inherent material properties are the design characteristics of a material. These properties have established values for specific materials under fixed conditions.

The management design considerations are involved with attributes that are of an add-on classification, and their addition or deletion is dictated essentially by the mission and the corresponding cost increase to implement the considerations.

Some of the specific characteristics will appear in more than one group.

These characteristics have a significant position in each group in which they appear. An example to illustrate this situation is the placing of the abrasion resistance characteristic in Group 2, Inherent Material Property Design Characteristics, and the placing of abrasion resistance improvement in Group 3, Management Design Characteristics. Abrasion resistance is an inherent property of any monolithic material that may be selected for a transparency; however, the abrasion resistance may be improved by the addition of abrasion-resistant coatings.

HELICOPTER TRANSPARENCY DESIGN CONSIDERATION GROUPS

The specific considerations by groups are as follows:

Group 1 - Primary Design Considerations

1. Optical performance
2. Abrasion resistance
3. Ease of maintenance
4. Installation and removal technique
5. Fail-safe construction
6. Crashworthiness/safety
7. Reliability
8. Life-cycle cost
9. Total weight
10. Structural integrity

Group 2 - Inherent Material Property Design Characteristics

1. Mechanical physical properties
2. Abrasion resistance
3. Fracture resistance
4. Chemical resistance
5. Ballistic spall
6. Resistance to thermal shock
7. Heat transfer
8. Fire resistance
9. Specific weight
10. Static discharge
11. Coefficient of thermal expansion
12. Optical properties including index of refraction, luminous transmittance, and haze

Group 3 - Management Design Considerations

1. Radar-reflective coating
2. Birdproofing
3. Antireflective coating
4. Rain removal techniques
5. Defogging/deicing techniques
6. Abrasion-resistance improvement
7. Polarization

Table III shows the three design groups with the assigned considerations or attributes. These considerations or attributes have been assigned a weighted ranking relative to the mission (type of helicopter) and the transparency location.

The weighted ranking of the transparency attribute was established through an analysis of the data compiled through interviews with the using personnel and the failure mode analysis conducted on various helicopters (see Table IV that follows and Tables IX through XVIII in Appendix I).

TABLE III. DESIGN GROUP WEIGHTED RANKINGS

		Helicopter Type by Mission												
		Trainer and Observation				Cargo				Utility				Attack[1]
Groups	Design Considerations	Wind-shields	Chin Bubbles	Eyebrow Windows	Side Windows	Wind-shields	Chin Bubbles	Eyebrow Windows	Side Windows	Wind-shields	Chin Bubbles	Eyebrow Windows	Side Windows	Wind-shields
Inherent Material Property Design Charac-teristics	Abrasion Resistance	1	2	3	3	1	2	3	3	1	2	3	3	1
	Fracture Resistance	1	2	3	3	1	2	3	3	1	2	3	3	1
	Chemical Resistance	3	3	3	3	3	3	3	3	3	3	3	3	3
	Ballistic Spall	3	3	3	3	1	2	3	2	1	2	3	2	1
	Resistance to Thermal Shock	3	3	[illegible]	3	3	3	3	3	3	3	3	3	3
	Heat Transfer (Tinting)	3	3	2	3	3	3	2	3	3	3	2	3	3
	Fire Resistance[2]	3	3	3	3	3	3	3	3	3	3	3	3	3
	Weight	1	2	3	3	1	2	3	3	1	2	3	3	1
	Static Discharge	3	3	3	3	3	3	3	3	3	3	3	3	3
Primary Design Consid-ations	Optical Quality	1	2	2	2	1	2	2	2	1	2	2	2	1
	Ease of Maintenance	1	1	2	3	1	1	2	3	1	1	2	3	1
	Installation and Removal Techniques	1	1	1	3	1	1	1	3	1	1	1	3	1
	Fail-Safe Construction	1	2	3	3	1	2	3	3	1	2	3	3	1
	Crashworthiness/Safety	1	2	3	3	1	2	3	3	1	2	3	3	1
	Reliability	1	2	3	3	1	2	3	3	1	2	3	3	1
	Life-Cycle Cost	1	2	3	3	1	2	3	3	1	2	3	3	1
Manage-ment Design Consid-erations	Radar Reflective Coating[3]	Yes	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes
	Birdproofing	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes
	Antireflective Coating	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes
	Rain Removal Techniques	Yes	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes
	Defogging/Deicing Techniques	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes
	Abrasion Resistance Improvements	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes
	Polarization	Yes	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes

Notes:

1. The present configuration of attack helicopters is such that the entire transparency may be considered a windshield (canopy) for purposes of this analysis.
2. The transparent materials currently utilized, including the transparent materials of foreseeable future, are either self-extinguishing or have a burning rate sufficiently slow that this property may be disregarded as a significant design consideration.
3. Radar reflective coating should be considered only for helicopters whose mission includes active tactical support in combat areas.

Legend

1 = Very important—consideration mandatory

2 = Important—not mandatory

3 = Not important

TABLE IV. PERSONNEL INTERVIEW SUMMARY

Problem Areas	Causes	Effect	Comments
Scratches and Abrasions	Windshield wipers. Hand wiping when dry wiping with improper material. Scratching with foreign object. Sliding window friction locks. Accumulated dust on rubbing strip.	Poor visibility. Excess glare and reflections. Refinishing causes distortions that frequently necessitate removal and replacement.	
Crazing	Using improper solvents and cleaning agents. Fuels contacting glazings. Sunlight. Prolonged stress.	Extreme glare and reflections. Frequent replacement.	
Cracking and Breaking	Cracked during field installation due to improper fit. Riveting replacement transparency. Maintenance personnel dropping tools or stepping on transparency (eyebrow windows). Sliding windows jamming and being forced open or shut. Air vents being rotated (circular air vents).	Repair work performed in accordance with technical orders.	If crack is short, it is stop drilled and laced with safety wire or "scab on" patches are applied. Replacement is constant problem. Interchangeability is impractical. Replacement details are trimmed and drilled to fit on assembly.
Static Discharge	Cleaning of transparency.	Picks up small electrical charge attracting dust and small foreign particles. Gradually dissipates.	Relatively unimportant to using personnel.

TABLE IV - Continued

Problem Areas	Causes	Effect	Comments
Heated Windshields	Hot air blast (turbine bleed air) for water and ice removal.	Severe distortion and warpage of windshield.	Field repair adding heat barrier plate used frequently (AG-1 helicopter).
	Electrically heated windshield constantly burning out.	Bubbling of interlayer. Loss of deicing capability.	
	Delaminations.	Windshield loses transparency in local areas. Delaminated areas become translucent and have milky appearance.	Repairs not practical. Replacements necessary.
Bird Strikes	Very infrequent due to low velocity and downwash of rotor.		Considered very minor problem by pilots. The infrequent strike usually bounces off windshield without penetrating.
Visibility	Tinting of windshields. Gold coatings on heated windshields.	Poor night visibility. Reduced visibility during daylight operations.	Glare in cockpit during night operations on many landings.
	Nontransparent structure in normal line of sight on side windows.	Large blocked-out visual areas due to location and proximity to pilot's eye position.	

TABLE IV - Continued

Problem Areas	Causes	Effect	Comments
Distortion	Attempted rework of scratches and/or pits.	Wavy or rippled appearance.	Original as-received transparencies are considered very good by pilots. Distortions observed by interviewer had not been noticed by pilots.

Notes:

The above breakdown of problem areas was the summary of interviews with 82 using personnel. Forty-five of those interviewed were maintenance personnel and various levels of management. The remaining 37 were pilots with an average helicopter flying time in excess of 1000 hours.

A general description for each of the design considerations is included as a guide for the formulation of specific detail design objectives.

OPTICAL PROPERTIES

The optical properties that should be considered are deviation, distortion, luminous transmittance, haze, and anomalies.

Deviation is the displacement of a beam of light as a result of passing through a transparency at an angle, and it is a function of the angle of incidence at each thickness of the material and index of refraction of the material. There is, therefore, a nominal deviation which is a product of the design, and variations from this nominal amount are caused by the two faces of the transparency not being parallel, by variations in material thickness, or by local contour variations. Deviation is normally not too serious a problem if it has been properly considered in the design.

Distortion, which is the rate of change of the deviation, is usually much more serious in a transparency. Distortion manifests itself as a ripple or wavy appearance of the object being viewed through the transparency.

Luminous transmittance is the ratio of transmitted light to incident light.

Haze is defined as the percentage of transmitted light which in passing through the transparency deviates from the incident beam by forward scattering.

Anomalies would be defined as minor optical defects such as imbedded particles, bubbles, or scratches that reduce visibility through the transparency, or would cause local distraction to the eye.

Specification limits for each of the four primary optical properties can be defined with numerical values. The values included in the different specifications vary with test methods, transparency use requirements, and design agency philosophy. In general, the test methods for luminous transmittance and haze have been standardized, and the results are sufficiently conclusive to be accepted throughout the industry. There are a myriad of test methods specified for measuring distortion and deviation and it is very difficult to compare either the requirements or the results of any two methods. Standardization of test methods is complicated by the variety of purposes of evaluation and the magnitude of discrepancies which can be tolerated. In general, flat sheet is evaluated by the projection of a beam of light through the sheet normal to the surface and measuring the magnitude of displacement of the beam at some established distance. Formed parts are mostly evaluated by photographing a grid board through the transparency and comparing that with a photograph of the grid board not influenced by the transparency. Grid-line displacements and grid-line angular

changes (shapes) can be evaluated. There are many variations of these two principles, and they are used interchangeably to some extent; i.e., grid boards used to evaluate flat sheet and light beam to evaluate formed parts. Some variations are the use of three-hole lens masks on the camera and holography principles. A single best test method does not exist, and the recommendation of a set of standard test methods is beyond the scope of this program.

The optical properties of transparencies are influenced by many factors, including the manufacturing processes utilized to fabricate the end transparency from the raw transparent material. These processes may cause scratches, uneven thinning, mark-off, and local contour variations. Adequate manufacturing and handling controls can therefore reduce these problem areas.

The optical properties of transparencies involved in the study program were considered adequate in the as-received state (see Table IV). The degradation of the optical properties invariably resulted from a mechanical abrasive action such as windshield wipers, improper cleaning technique, or foreign objects striking the transparency.

In addition to the basic optical quality of the transparency, other factors affecting the vision include the transparency thickness, the angle of incidence, and the formed contour.

The transparency thickness is dictated by the structural design. The formed contour should be optimized by large form radii approaching a flat plane with the angle of incidence approaching zero degrees. High angles of incidence not only are objectionable from a deviation and distortion aspect, but tend to cause distracting reflections.

Flexing and warping of transparencies obviously change the angles of incidence, and the resulting variations in optical properties are objectionable to using personnel. Flexing and warping are controlled by transparency thickness and the supporting structure.

VISUAL REFLECTION

The reduction of visual reflection from aircraft transparencies is important for several reasons. Internal reflections of cockpit lighting (instruments, map lights, etc.) emanate from the interior and exterior glass/air interfaces of monolithic transparencies. Reflectance sites are increased by the incorporation of multiple plies and/or electrically conductive coatings. This internal reflectance, often referred to as glare, was cited as a source of considerable distraction by many pilots interviewed. Cockpit reflectance at night is particularly bad. External light sources such as landing lights cause added glare during night landings in the OH-58 helicopter.

Many pilots commented on the problem of distracting reflections encountered during night flights in the AH-1G helicopter. Pilots of all cargo class helicopters outfitted with electrically heated windshields regarded night vision impairment due to reflectance as a significant problem.

The second important aspect of visual reflection from aircraft transparencies relates to sunlight reflectance. Reduction of visible flash is an important survivability factor for helicopters operating in a combat area. Visible flash can reveal the approach of an aircraft long in advance of engine/rotor noise or, in the case of low-flying helicopters, radar.

Antireflective coatings have been used for many years on camera lenses, optical windows, instrument faces, etc. Difficulties exist in applying the technology developed for coating these relatively small glass surfaces to larger contoured substrates. The deposition of magnesium fluoride and related materials requires higher processing temperatures than most plastics can accommodate.

The most promise appears to lie with several new coatings which have resulted from recent development efforts. At least one such coating has been applied to UH-1 windshields and AH-1G cockpit transparencies for evaluation.

The results of these evaluations will establish the relative merit of such coatings. The test articles are coated on both internal and external surfaces. The external aircraft environment is quite different from, and much more severe than, the internal environment. Coating durability has traditionally been a problem with antireflective coatings subjected to the rigorous aircraft environment.

Coating of the internal surface only would help alleviate the severe cockpit reflectance experienced during night landings in some aircraft. This problem is attributed to the multiple-image source at the internal glass/air interface. The benefit gained by the single surface coating would have to be weighed against many factors such as cost, durability, added maintenance, etc. The coating of one surface has been rated at 20 percent of the efficiency obtained with both surfaces coated.

At the present time, antireflection coatings are developmental in nature. The level of activity and preliminary results of some new coatings indicate that a satisfactory coating may soon be available.

SOLAR RADIATION

The transparent area of helicopters is generally larger than that of a fixed-wing aircraft; therefore, the effects of solar radiation are somewhat greater. In order to reduce the heat transmitted through the transparencies, the technique of tinting has been utilized. This tinting technique does cause a loss of visibility, particularly during night operations. The tinting of transparencies is at best a compromise. There have been investigations to determine other techniques of reducing the solar radiation through transparencies, such as infrared reflective coatings,

the use of photochromic materials, and the use of electrochromic materials. The infrared filtering does reduce the radiation without a corresponding reduction in visibility; however, the filtering effect is efficient for only one angle of incidence.

The photochromic materials offer a substantial color change only during periods of high solar intensity. The disadvantage is the slow reaction time and the fatigue of the materials.

The electrochromic materials have not been developed to a state of practicality at this time. These materials do offer the greatest potential in that the pilot may adjust the degree of shading desired.

POLARIZATION

The study program did not disclose any use of polarized light. The operational environment of a helicopter should dictate the consideration of techniques for polarizing the windshields and other observation transparencies.

The technique of an individual having control of the polarizing plane to eliminate reflected glare would be desirable. This technique is currently available in many commercial airliners in the form of an independent polarizing panel that is snapped in place by the pilot or copilot.

ABRASION RESISTANCE

General

Abrasion resistance may be defined as the ability of a material to windstand mechanical action such as rubbing, scraping, or erosion from particle impingement that tends to remove material from its surface.

The abrasion resistance of a helicopter windshield transparent material plays a vital role in maintaining flyable optics in service. It is desirable to utilize a material of highest abrasion resistance which is also capable of meeting the other transparency criteria.

The location within the aircraft and usage of each transparency create varying levels of acceptable resistance to abrasion.

Of primary importance is the maintenance of the stringent optics of windshields and other primary viewing areas such as chin bubbles. A large number of transparency restorative and replacement actions identified during the data collection effort were related to abrasive damage. This point is illustrated in Table XIV of Appendix I. The extent of such actions on glazings other than windshields was less, due to such factors as the absence of windshield wiper action, the position and location of the transparency, and less critical optical requirements.

Abrasion Resistance of Glazing Materials

The most commonly used aircraft glazing materials can be comparatively ranked in order of abrasion resistance as follows:

1. Glass
2. Allyl diglycol carbonate (CR-39)
3. Acrylic
4. Polycarbonate

Composites of these basic materials are also used in various aircraft transparencies. Electrically heated windshield panels utilize glass-to-glass, glass-to-acrylic, and allyl diglycol carbonate-to-acrylic combinations.

The hardness of glass minimizes the potential of abrasive-type damage. Glass faced transparencies with frontal mounting positions and windshield wiper usage have best resisted abrasive action.

The transparencies which utilize allyl diglycol carbonate material rank next in abrasion-resistant performance. The allyl diglycol carbonate material is utilized primarily as the exterior facing ply on laminated electrically heated windshields.

Helicopters that are designed with plastic transparencies that open by virtue of a sliding motion should avoid locks on the transparency that work on a friction-type lock basis. This friction-type lock invariably results in an abraded or scored area of a size commensurate with the area of the friction lock and the travel distance of the sliding transparency. A mechanical-type lock which holds the transparency other than on a friction basis is recommended.

Abrasion-Resistant Coatings

One approach to improving the abrasion resistance to plastic transparencies is through the application of thin, protective coatings. There are a number of these coatings in current use protecting transparencies in fixed-wing aircraft, ground vehicles, and fixed structures. Examples of these coatings are Owens-Illinois Glass Resin, DuPont Abcite, and General Electric MR-2000. There is also a great deal of work throughout the industry to develop new and improved coatings.

These coatings are particularily useful in the protection of polycarbonate. Not only do they significantly improve the abrasion resistance, but they also offer a measure of protection from the fluids to which polycarbonate is so sensitive. One problem with the current coatings is that they are difficult or impossible to repair if they become scratched or otherwise damaged. This is not so significant on polycarbonate because it is itself so difficult to resurface.

Another area of concern with the current coatings is the universal susceptibility to cycles of high humidity combined with elevated temperature. None of the coatings are currently capable of standing up under the MIL-STD-810 test cycles, but these cycles are probably unrealistic because some of the coatings have survived well under service conditions.

Some test data showing abrasion-resistance characteristics of hard coated test specimens is available in Technical Report AFML-TR-72-117 mentioned earlier.

Test Methods

An element of the abrasion resistance of transparent plastic material can be measured through the use of an abrader in accordance with ASTM Designation D1044-56. However, some materials behave differently with the different forms of abrasive action, and techniques of measuring the abrasion resistance of transparencies that more closely simulate the actual abrading environment are being developed. One of these techniques being developed is documented in Technical Report AFML-TR-72-117, Design Criteria, Transparent Polycarbonate Plastic Sheet, dated August 1972.

The characteristic that is measured before and after the use of the abrader is the haze level. This testing is accomplished with a hazemeter as specified in Method 3022 of Federal Test Standard 406.

CHEMICAL RESISTANCE

The chemical resistance of an aircraft glazing material is an important measure of its ability to perform in the service environment. Of particular interest is the compatibility with chemicals and fluids routinely used in aircraft operation and maintenance functions. A ranking of commonly used glazing materials for overall chemical resistance and comments regarding general chemical properties would show the following (in descending order of resistance):

1. Glass, MIL-G-25667:

   Glass is inert to most known chemicals at temperatures below its softening point. Hydrofluoric and concentrated phosphoric acids are known solvents of glass.

2. Polyester, MIL-P-8257:

   Case polyester is more resistant to chemical attack than the acrylics. The material has good stress-solvent crazing properties when tested with isopropyl alcohol or lacquer thinner.

3. Stretched Acrylic, MIL-P-25690:

   Stretched acrylic has good stress-solvent crazing resistance when tested with isopropyl alcohol. The modified acrylic

MIL-P-8184 base material used to produce stretched acrylic is described below.

4. Modified Acrylic, MIL-P-8184:

Modified acrylic is more highly cross linked and is generally more chemical resistant than MIL-P-5425 cast acrylic. The MIL-P-8184 material has good stress-solvent crazing resistance when tested with lacquer thinner and isopropyl alcohol.

5. Cast Acrylic, MIL-P-5425:

Cast acrylic has poor resistance to stress-solvent cracking when tested with lacquer thinner or isopropyl alcohol. The acrylic is unaffected by most inorganic solutions, mineral and animal oils, and low concentrations of alcohol. Oxidizing acids affect the material only in high concentrations. Acrylic is unaffected by paraffinic and olefinic hydrocarbons, amines, alkyl monohalides, and esters containing more than 10 carbon atoms.

Lower esters, aromatic hydrocarbons, phenols, aryl halides, aliphatic acids, and alkyl polyhalides usually have a solvent action.

6. Polycarbonate, MIL-P-83310:

Polycarbonate has very poor chemical resistance to many substances found in an aircraft environment. The material has good resistance at room temperature to water, dilute inorganic and organic acids, solutions of neutral and acid salts, vegetable oils, aliphatic hydrocarbons, ethers, and alcohols. Polycarbonate is readily dissolved by certain halogenated solvents such as methylene chloride, 1, 2 dichloroethane, and chloroform. Plasticization and crystallization can result from contact with partial solvents such as low-molecular-weight aldehydes, and ethers, ketones, esters, aromatic hydrocarbons, and perchlorinated hydrocarbons. Chemical attack ranging from partial to complete destruction of the material occurs in contact with alkali, alkali salts, amines, and ozone. The material has very poor resistance to stress-solvent crazing. Crazing can be induced at high stress levels by low-molecular-weight hydrocarbons and alcohol. Polycarbonate is rapidly attacked by lacquer thinner, but it resists isopropyl alcohol during stress-solvent testing.

FRACTURE RESISTANCE OF MATERIAL

There are significant differences in the fracture resistance of the various materials used for transparencies. Glass is particularly subject to breakage. A significant improvement over glass is achieved with as-cast acrylic, and when the acrylic is stretched in accordance with MIL-P-25690, it significantly increases fracture resistance. Polycarbonate has the greatest resistance to fracture of all common helicopter glazing materials.

The fracture resistance of presently used aircraft glazing materials is adequately specified for general-purpose use by applicable military specifications. A high incidence of repair and replacement actions documented for helicopter glazings was identified in the chipped, cracked, and broken classifications. It is felt that these service failures are as sensitive to design control as to material specification control. The fracture resistance of presently used glazing materials is not likely to increase in the near future. Design attention to improvements in edge attachments, glazing material and thickness selection, processing for minimized internal stress, and installation methods offers promise of reducing the incidence of fracture-related failures. Accidental damage incurred during field service will likely maintain a high level of chipped, cracked, and broken classification actions. Improper installation techniques, tools dropped through glazings, flying debris, and inadvertent impacts while loading cargo or from troops wearing back packs will continue to result in such damage.

The mission requirements for certain helicopter classes can require other specific properties relating to fracture resistance. All aircraft operating in a combat area can benefit from the incorporation of bullet-resisting or as a minimum, antispalling transparencies. Higher performance present-day fixed-wing and possibly future helicopter classes require birdproof capability in the forward positioned glazings. These fracture-resistance related requirements are discussed separately under the BALLISTIC PROPERTIES and BIRDPROOFING headings.

BIRDPROOFING

Present helicopter transparencies are not designed for bird impact resistance properties. Infrequent bird impacts occur in helicopters operating under present mission parameters (see Table IV). The infrequency of bird strikes was established in the interviews with experienced pilots. Bird strikes that did occur most frequently struck the helicopter rotor or structure other than transparencies. The reported transparency bird strikes usually did not result in fracture of the transparency.

Therefore, the incorporation of birdproof forward glazings does not appear to be a valid requirement for current helicopter operations. Mission requirements and performance characteristics of future helicopter designs may require such protection. Technology pertaining to birdproof glazings for high-performance fixed-wing aircraft exists and can be utilized for designing helicopter glazings when required. With existing technology, a significant weight penalty is paid for bird impact resistance.

BALLISTIC PROPERTIES

General

It would be desirable for aircraft operated in combat areas to be provided with armor protection in the transparent vision areas as well as opaque cabin areas. Helicopter aircrew protection has been only partially effective since traditional helicopter glazing materials do not offer significant levels of bullet-resisting capability. Most helicopters have larger transparency areas than fixed-wing aircraft.

The weight and spatial accommodation required to add transparent armor has been prohibitive. For this reason, the selection of helicopter glazing materials for ballistic properties has been limited primarily to their relative spall resistance.

Recent developments in high-performance glass/plastic transparent armor composites have yielded greatly improved performance capabilities. Such glass/plastic composites offer significant reduction of areal density and improvements in nonspalling characteristics.

The ballistic properties of the traditional helicopter glazing materials and glass/plastic composites are summarized below.

Acrylic

Acrylic does not offer ballistic defeat capability at any reasonable thickness. The poor crack propagation resistance of as-cast acrylic results in catastrophic glazing failure upon ballistic penetration.

Stretched acrylic (MIL-P-25690) has improved crack propagation and impact strength. Stretched acrylic aircraft glazings have demonstrated resistance to catastrophic failure upon ballistic penetration. The spalling characteristics are undesirable but considerably better than any cast acrylic or glass.

Polycarbonate

Polycarbonate (MIL-P-83310) has better ballistic properties than any of the acrylic materials. It does not offer significant ballistic defeat capability at reasonable thicknesses, but the nonspalling characteristics are very good. The material exhibits unusual toughness and effectively resists crack propagation. Projectile penetration often results in a hole smaller than the projectile with minimal glazing material removal. Polycarbonate has been extensively used as the backing ply of high-performance glass/plastic composite armor.

Laminated Glass

Laminated glass glazings are utilized primarily in cargo class helicopters. Various types and tempers of glass are employed in these glazings. The thickness of typical laminated glass glazings, whether heated or unheated, is not considered to have an armor function and offers only the most minimal ballistic defeat capability. The spalling characteristics of laminated glass are very poor. A ballistic strike on a laminated glass glazing can create a very large amount of injurious spall even without completely penetrating the assembly. Post-hit visibility is a problem through glazings incorporating fully tempered, small dice glass. Laminated bullet-resistant glass (MIL-G-5485) is not feasible for helicopter use. This material has a density of approximately 13 pounds per square foot per inch of thickness. Several inches of MIL-G-5485 glass are required for adequate protection levels. Backside spalling is a problem also associated with laminated glass armor and can be very severe if the glazing is overpowered and penetrated.

Laminated Glass/Plastic

Laminated glass/plastic glazings are also used primarily in cargo class helicopters. Various types and tempers of glass are employed in the outer face sheet of these glazings. Stretched acrylic is the preferred backing ply on presently used glazings. Typical glass/plastic glazings of the thickness presently in use are not considered to have an armor function and offer only the most minimal ballistic defeat capability. The spalling characteristics of the composite are somewhat better than those of laminated glass. Most ballistic strikes can be anticipated to penetrate the present laminates, thus creating a large amount of unjurious spall.

Advanced Glass/Plastic Transparent Armor

The aforementioned high-performance glass/plastic armor composites represent the first transparent glazings offering reasonable performance-to-weight ratios. Army-sponsored contracts are presently under way to design and fabricate primary and auxiliary glazing concepts of such armor for specific helicopters.

The glass/plastic armor composites utilize borosilicate or soda-lime glass facings as the hard layer to break up the projectile. A polycarbonate backing ply is adhered to the glass with a cast-in-place or sheet interlayer. The plastic backing absorbs the remaining energy and prevents passage of projectile or armor spall.

Specific armor performance characteristics for various configurations of glass/plastic armor are classified.

Promise of further performance gains is indicated by Army-sponsored development work in magnesium oxide and aluminum oxide transparent ceramic facing materials. These high-hardness materials offer improved ballistic properties, particularly when protection is required against armor-piercing ordnance.

RESISTANCE TO THERMAL SHOCK

Aircraft transparency materials have been evaluated for many installations to demonstrate resistance to thermal shock. Monolithic plastics such as acrylics, polyesters, and polycarbonate have demonstrated the ability to resist rapid temperature changes within the limits anticipated during flight.

Design allowables for the glazing materials, edge attachments, and installation techniques have thus been established. Qualification test of aircraft glazings made from these proven monolithic materials is limited to rapid descent tests during flight testing. In some instances no thermal shock test is deemed necessary.

Laminated transparency materials tested to comply with MIL-G-25871 for glass or MIL-P-25374 for modified acrylic are required to withstand -65° to 161°F and -40° to 212° F temperature changes, respectively. These tests appear to be adequate to insure service performance of helicopter glazings in all usage classes.

Laminated transparencies incorporating electrically heated coatings should be subjected to additional thermal shock acceptance test procedures. The test article is stabilized at -65°F, and full operating voltage is applied until the window sensor indicates that design temperature has been reached. The electrical power is then removed, and the test article is allowed to stablize at room temperature.

The high incidence of service failures of electrically heated windshield panels indicates that substantial improvement in the processing techniques is required. The primary failure mode on heated windshields is a delamination that manifests itself as a translucent milky area. This failure is usually the result of a thermal shock coupled with the low adhesion between the face sheets and the interlayer material.

WEIGHT

The weight of a given size transparency is determined by the specific gravity and thickness of the glazing material. The specific gravity of available glazing materials is controlled within narrow ranges for each type of material and can be ranked accordingly (see Table V). The thickness of a glazing is controlled by design factors and the physical properties of each material. The low comparative specific gravity of acrylic favors its use wherever possible. Monolithic forms of plastic generally offer better strength-to-weight ratios than laminated composites, thus reducing comparative weight.

Glass has a low strength-to-weight ratio and represents the heaviest commonly used glazing material. Laminations of glass and plastic can offer reduced weight. Transparency weight should be the minimum practical weight consistent with the overall requirements specified.

TABLE V. SPECIFIC GRAVITY OF COMMON HELICOPTER GLAZING MATERIALS

Material Type	Military Specification	Specific Gravity
Cast acrylic	MIL-P-5425	1. 18-1. 20
	MIL-P-8184	1. 18-1. 20
Stretched acrylic	MIL-P-25690	1. 18-1. 20
Cast polyester	MIL-P-8257	1. 31
Polycarbonate	MIL-P-83310	1. 20
Glass	MIL-G-25667	2. 51

HEAT TRANSFER CHARACTERISTICS

The heat transfer characteristics of common aircraft glazing materials are presented in Table VI. The required heat transfer characteristics of the transparencies depend upon their location in the helicopter, the type of transparency construction, and the helicopter mission requirements. No specific heat transfer properties are required except that they shall be known with sufficient accuracy so that heat transfer studies made in conjunction with design of heated transparencies or design of cabin airconditioning systems can be performed within the required accuracy requirements.

TABLE VI. COEFFICIENT OF THERMAL CONDUCTIVITY OF COMMON AIRCRAFT GLAZING MATERIALS

Material Type	Specification	Coefficient of Thermal Conductivity ($Btu/hr/ft^2/^oF/in.$)
Cast acrylic	MIL-P-5425	1.30-1.70
Modified cast acrylic	MIL-P-8184	1.20-1.55
Stretched acrylic	MIL-P-25690	1.15
Polyester	MIL-P-8257	1.56
Polycarbonate	MIL-P-83310	1.35
Glass	MIL-G-25667	6.5

RAIN REMOVAL METHODS

General

There are three basic rain removal systems employed today for helicopter transparencies:

1. Mechanical windshield wiper

2. Bleed air jet blast

3. Rain repellants

The rain repellant system can be further subdivided as follows:

1. In-flight applied

2. Ground applied

Helicopters utilized for trainer and observation missions generally are not fitted with rain removal systems. These helicopters rely on airflow to blow rain from the transparencies. The effectiveness of this removal relates directly to the air velocity over the transparency which is created by the forward velocity and/or the downwash from the main rotor in a hover attitude.

The rain removal systems employed on the helicopters were the bleed air jet blast and the mechanical windshield wiper. However, during the personnel interview data collection it was reported that a few isolated training missions had been accomplished using the ground-applied repellants. Due to the limited amount of data regarding these ground-applied repellants, no valid observations regarding the effectiveness of these repellants can be made. There is development work currently under way which shows promise for upgrading the more desirable ground-applied repellant coating. The progress of this development work was discussed at the Air Force Materials Symposium on Transparent Materials at the 1970 Miami Conference.

Bleed Air Jet Blast Rain Removal System

The AH-1 Cobra attack helicopter employs the bleed air jet blast rain removal system. This system is considered effective by using personnel. Malfunctions of the turbine bleed air control system and improper usage techniques have resulted in many windshield replacement actions. The 0.10-inch-thick acrylic center windshield has been severely warped or even melted during such occurrences. This type of malfunction and subsequent replacement action are indicated in Table IV. It might be noted that in Tables IX and X there is no reference to this type of malfunction and corresponding maintenance action. This lack of correlation between interview data and computer data may be explained by an inadequate description in the failure code charts.

Field maintenance actions have resulted in the installation of a heat barrier plate approximately 6 inches by 10 inches that covers the forward portion of the AH-1 center windshield immediately adjacent to the outlet of the bleed air duct.

Windshield Wiper Rain Removal Systems

Mechanical windshield wiper rain removal systems are used extensively on windshields of helicopters in the cargo and utility classifications. The operational function and visibility in rain were reported to be good for all helicopters so equipped.

The interviews and analysis of repair and replacement actions conducted clearly reveal that the present plastic aircraft glazing materials are incompatible with windshield wipers. Glass is the only glazing material which is capable of resisting damage from wiper blade abrasion. A preponderance of UH-1 windshield reworks and replacements were attributed to wiper-induced damage. UH-1 windshield panels made with MIL-P-8184 or MIL-P-25690 acrylic require extensive surface restoration or replacement after very short periods of wiper usage. Wiper operation of an unauthorized nature for fog or frost removal, or inadvertent dry running, frequently results in severe nonrestorable scratching of the glazing.

Allyl diglycol carbonate material meeting L-P-516 Type G3 and other similar modified polyester cast sheet material have been employed in aircraft glazings. The allyl diglycol carbonate primarily has been used as an outboard face ply in laminated plastic electrically heated cargo helicopter windshields. The abrasion resistance of allyl diglycol carbonate is superior to the acrylic materials used for aircraft glazings. It is not adequate, however, to resist wiper abrasion damage. Polycarbonate has the lowest abrasion resistance properties of the aircraft glazing materials and cannot be used with windshield wiper systems.

There are extensive development efforts under way to provide abrasion resistant coatings for the various plastic glazing materials. Details of these programs and the present state of the art are discussed under the heading ABRASION RESISTANCE.

DEFOGGING AND DEICING METHODS

A variety of methods are employed on present helicopter transparencies to provide defogging and/or deicing functions. The methods range from simple fans to accomplish defogging only to sophisticated heated glazings which incorporate electrically conductive films. Mission requirements and existing helicopter characteristics have dictated the type of systems presently used.

Present aircraft anti-icing, defrosting, and defogging systems for transparent areas are designed to military specification MIL-T-5842 requirements.

All trainer class and most of the light observation class helicopters have simple defogging fans and no deicing features. The more sophisticated OH-58A has a ducted type hot-air defogging system, but no deicing capability.

The utility class helicopters also have ducted type hot-air defogging systems without deicing capability.

The AH-1G attack helicopter uses a jet blast bleed air ducted system directed onto the exterior surface of the windshield for deicing and rain removal. Ducted hot air is used for defogging of the interior surfaces.

Cargo class helicopters are the only aircraft which presently utilitize electrically heated deicing windshields. The cargo helicopter is least affected by the weight penalty imposed by the heated glazings and associated electrical power and control equipment.

The next-generation utility transport helicopter (UTTAS) may likely be the first utility model to incorporate electrically heated glass-plastic windshields.

Combining the electrically heated concept with high-performance glass-plastic transparent armor constructions appears to be feasible for the next-generation attack helicopter. The present AH-1G Cobra attack helicopter would be very difficult to modify. The AH-1G pilot relies on flying visibility through the gunner's cabin windows as well as his own. The viewing angle of incidence is high. Optical deviation and distortion through a thicker, multiple-layer heated glazing would be considerably increased.

The observation and trainer class study aircraft typically have large, highly contoured windshields or bubble-type cockpit enclosures. The missions of this class aircraft do not require the use of electrically heated anti-icing/fogging windshields. Future advanced concepts of observation helicopters may incorporate windshield glazings more adaptable to this type of construction. Mission requirements will dictate incorporation of electrically heated glazings; however, it is not anticipated as a requirement in training class helicopters.

Electrically heated glazings generally result in heavy penalties in optical quality (distortion, light transmission, reflections, etc.), weight, initial and replacement costs, and limited service life. They should be specified only when the contribution to mission requirements is sufficient to balance these penalties.

A paper prepared by Phillip A. Miller[a] of Sierracin Corporation contains a significant number of design considerations that should be evaluated in establishing the design of electrically heated windshields.

STATIC DISCHARGE

As dielectric surfaces of an aircraft, transparencies undergo strong static electrification effects from frictional contact with atmospheric particles such as dust, snowflakes, and raindrops. An aircraft moving through air results in an interaction between the body and the air molecules. Electron transfer occurs between the impinging particles and the aircraft's surface. An electrical charge (either positive or negative) is acquired by the aircraft with an equal and opposite charge being carried away by the particles. The P-static (precipitation-static) phenomenon can result in the accumulation of large-magnitude static potentials. depending on the glazing size, its dielectric properties, and the charging rate. Static charging occurs to some degree during each aircraft flight, although the presence of charging is not usually detected until one of the following functional problems occurs.

On aircraft having monolithic or laminated nonheated glazings, the common functional problems experienced are:

1. Radio frequency noise from static discharge

2. Visual impairment from static discharge streamering or St. Elmo's fire

Aircraft fitted with electrically heated glazings share the aforementioned problems as well as being subject to the following:

1. Dielectric failure and punch-through (occurs with a thin outboard ply and the presence of a high local charge gradient, say, to an imbedded metallic sensing element)

2. Radio frequency noise from induced transients in the inboard heated coating

3. Induced transient damage to inboard heated coating and solid-state control devices

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[a] Miller, Phillip A.: "Anti-icing Aspects of Helicopter Windshield Design." Paper presented at Helicopter Icing Conference, Ottawa, Canada, May 23-26, 1972.

It is significant to note that static charge accumulation levels are apparently low for helicopter flight conditions. Pilots interviewed did not consider this to be an operational problem of consequence.

Only one example of St. Elmo's fire discharge was related.

No reliable permanent antistatic coating system has yet been developed, and development effort continues in this area. The desirability of combining coating functions for antistatic, antireflection, abrasion resistance, etc., is obvious. Static discharge remains a serious problem in high-performance aircraft. The problem is minimal in helicopter flight conditions and should remain so unless dramatic improvements are made in helicopter flight speeds.

REDUCED RADAR REFLECTIVITY

The ability of a manned aircraft to penetrate enemy defenses is enhanced by low radar cross section. The two areas of an aircraft reflecting most of the radar returned to a receiving station are the engine and cockpit. The cockpit of most aircraft represents a sizeable area capable of radar return when the transparencies transmit radar. Therefore, aircraft windows and canopies are sought which will prevent the transmission of radar.

Present glazing materials transmit radar; however, several solutions to the problem are being studied. Two means of preventing radar transmission of transparencies are to absorb the radar or to reflect the radar in a metal-like manner. Thin films of various materials applied to the transparency are being evaluated for absorption or reflective properties. Problems relating to complex processing and coating durability have limited the utilization of radar cross section reduction (RCSR) coatings. The best available RCSR coatings have been applied to aircraft glazings for test and evaluation. These prototype glazings are presently installed on high-performance fixed wing aircraft. The relative merits of the coatings are yet to be determined.

RELIABILITY (SERVICE LIFE)

The reliability of aircraft transparencies pertaining to service life is an important aspect of maintaining ready-to-use aircraft status and a high standard of operation.

Consideration should be given to certain changes appropriate to increase the reliability of present aircraft glazings. The most important changes briefly summarized below are treated in more detail elsewhere in this report:

1. Monolithic plastic used in many glazings is extremely thin. This results in a high incidence of replacements due to breakage.

2. The outer surface of many glazings is not compatible with the service environment. The use of windshield wipers on plastic surfaces best typifies this reliability problem.

3. Changes are required in the materials and/or design of laminated glazings to increase in-service reliability. Qualification and acceptance test procedures better capable of indicating reliable performance are needed.

4. Delaminations and burn-out or other malfunction of electrically conductive coatings frequently destroy the usefulness of laminated glazings.

EASE OF MAINTENANCE

Maintenance procedures for aircraft transparencies should require as little specialized equipment and procedures as possible. Present procedures and equipment outlined in both the General Aircraft Maintenance Manual, TM 55-1500-204-25/1, and specific aircraft technical maintenance manuals appear to meet these requirements.

A high level of competence and universally used maintenance and repair procedures were found at the various facilities visited. Such a situation attests to the adequacy of both the written procedures and personnel training methods for performing such actions.

Maintainability of future aircraft transparencies should remain an important consideration during the design and material selection phases of such efforts. Field or depot repair procedures are required for laminated transparencies. Delaminations of such panels, whether plastic-to-plastic, glass-to-glass,or glass-to-plastic, are presently not considered to be reparable. The laminated glazings are more expensive, particularly when an electrically heated function is included for anti-icing/fogging requirements. An effective repair procedure for delaminations in such parts would result in considerable cost savings.

It may be necessary to initiate specific procedures for daily care of some of the concepts presently being considered. These may include special methods of cleaning, as have been initiated on occasion for monolithic polycarbonate or unprotected RCSR coatings, or daily applications of protective solutions such as "Total Finish" to increase abrasion resistance.

INSTALLATION AND REMOVAL TECHNIQUES

Presently used installation and removal techniques for helicopter glazings range from efficient simple actions to those requiring excessive manpower and considerable expertise.

In general, smaller window glazings are provided in the trimmed and predrilled condition. The use of riveted glazing attachments results in a high incidence of breakage with thin acrylic glazings. Rivets are also difficult to remove and reinstall when replacing glazings. An entire door assembly is sometimes replaced in the field rather than replace a defective door glazing.

The larger replacement helicopter glazings such as bubble canopies, windshield panels, chin bubbles, etc., are provided oversize and undrilled. This is presently required due to the disparity of frame configuration from aircraft to aircraft.

Fasteners, whether rivets or screws, are commonly drilled out. The old sealant is removed from the frame, and the replacement panel is fitted, marked, and trimmed.

The panel is repositioned, and the hole positions are either marked or are drilled in position. Difficulty is often experienced in the hole location and drilling operations. The frames can be damaged while drilling out the original fasteners or the new fastener holes with the replacement glazing in position.

After the drilling of attachment holes, the sealant is applied and the glazing is secured in place with new fasteners.

The replacement of such articles requires specialized skills and techniques. Data analyzed for the number of maintenance man-hours required to replace a UH-1D windshield helps to demonstrate this fact. A windshield replacement at a repair facility which performed this function one time required a total of 40 man-hours. The same replacement required only 5 man-hours at a more experienced repair facility which had performed 28 such actions.

A more efficient installation and removal technique will rely primarily on the innovative design of a more universal glazing to frame fit and attachment concepts Accomplishing such a goal without adding significantly to the cost of the original aircraft will be difficult. The present trim and drill to fit requirements are dictated by deformation occurring in the framing structural members due to flight loadings as well as the variations found in new aircraft.

The following guidelines for the design of helicopter transparencies will simplify the installation and removal procedures for present types of glazings:

1. The use of rivets to attach transparencies should be avoided. Bolt attachment into nut plates is preferable.

2. Spacers, collars, or shoulders should be used to prevent excessive tightening against the transparency.

3. Provisions should be made to prevent excessive stresses due to relative distortions between the transparency and the frame.

REPAIR TECHNIQUES

In general, glass transparencies that develop optical defects in the field are considered to be nonreparable.

Polyester and polycarbonate transparencies that develop minor optical defects in the field may be repaired using the manufacturer's instructions. These materials are usually quite difficult to repair (optical discrepancies such as scratches, haze, or pits), and the success ratio is very low.

Acrylic transparencies may be successfully repaired following the instructions in the Department of the Army Technical Manual, TM 55-1500-204/1, Chapter 4, Section III.

Cracks that occur in acrylic transparencies on helicopters may be repaired following the procedures outlined in the above-referenced technical manual. These repairs should be considered temporary, and the transparency should be replaced at the earliest practical time.

Delamination of laminated transparencies is considered to be nonreparable, and the delamination transparency should be replaced when the delaminated area extends into the critical viewing area.[a]

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[a] Critical viewing area may be defined by the procuring activity and takes into consideration the edge effect and areas of the transparencies through which a minimal number of observations are made.

LIFE-CYCLE COSTS

Life-cycle cost factors must be considered when designing aircraft transparencies. Material selection and design considerations made using such data can be expected to yield a transparency better capable of performing at the lowest cost level. The importance of relating the total cost of original procurement plus required total maintenance costs to the effective service life can be readily understood.

A low-cost transparency which requires extensive maintenance with average or better life can be more expensive than a higher cost panel which requires little or no maintenance over the same life period. Data collected during the reported effort was not of the nature required for life-cycle cost determinations. No attempt was made to assign relative ratings to typical transparencies for this reason.

FAIL-SAFE CONSTRUCTION

Fail-safe capability is required for all forward-vision windshields and other transparencies looked through by the pilot or copilot during flight. Fail-safe performance levels will vary with individual aircraft designs and mission requirements. The extent or magnitude of allowable damage which does not endanger flight safety must be considered for each design. No material or composite should be used whose failure as a result of foreign object impingement or other damage would result in complete loss of forward visibility for the pilot. The extent of allowable panel removal due to breakage under such conditions must be evaluated with regard to helicopter controllability and the effect of aerodynamic forces or adverse environmental conditions on the pilot.

Birdproofing and ballistic defeat capability where required represent the highest levels of fail-safe capability for aircraft transparencies.

CRASHWORTHINESS/SAFETY CONSIDERATION

The crashworthiness of aircraft transparencies and relative safety afforded to aircrews and passengers are influenced by several factors. The strength of the glazing material, edge attachment, and aircraft structure, as well as the location of the glazing within the aircraft, all influence the likelihood of fracture during a crash.

The circumstances surrounding aircraft crashes are random and unpredictable. The design of aircraft transparencies for crashworthiness and safety considerations is dictated by such conditions imposed during any survivable crash. The selection criteria therefore relate to the fracture resistance of candidate glazing

materials. Of particular interest is the fracture characteristics of the material once failure has occurred. The requirement for providing safety glazings for use in proximity to aircrews and passengers has long been considered in aircraft design. Glazing materials which when broken result in jagged pieces, sharp piercing splinters, or other potential projectiles are unsafe and should not be used. It has been reported that a fracture in some types of chemically strengthened glass will result in catastrophic shattering of the total panel surface into such small pieces as to make the panel opaque.

Polycarbonate offers superior breakage resistance and does not tend to splinter when fractured. Its use as an aircraft glazing material has been limited by disadvantages relative to optics, solvent resistance, abrasion resistance, and cost.

Laminated glazings, whether of glass, plastic, or a combination thereof, generally maintain better integrity when penetrated or are otherwise fractured. Heat or chemically strengthened glass offers controlled breakage patterns and dices into less injurious granules.

Crashworthiness and safety considerations to the aforementioned criteria remain as an important function in evaluating new aircraft glazing materials as they become available.

FIRE RESISTANCE

The fire resistance or relative flammability of aircraft glazing materials is an important consideration since the glazings represent sizeable areas in close proximity to the aircrew.

The availability of suitable glazing materials is very limited, and selection is largely dictated by factors other than flammability. The flammability characteristics of commonly used glazing materials are shown in Table VII.

TABLE VII. FLAMMABILITY CHARACTERISTICS OF COMMON AIRCRAFT GLAZING MATERIALS

Material	Military Specification	Burning Characteristics	Maximum Rate of Burning (inches/min)	Test Specification
Glass (Plate)	MIL-G-25871	Nonburning	-	N/A
Polycarbonate (Extruded)	MIL-P-83310	Self-extinguishing	-	ASTM D2863-70 ASTM D635
Polyester (Cast)	MIL-P-8257	Burning	1. 0-2. 0	Federal Standard 406 Method 2021
Acrylic (Cast)	MIL-P-5425	Burning	1. 5-2. 5	Federal Standard 406 Method 2021
Acrylic (Modified Cast)	MIL-P-8184	Burning	1. 0-1. 5	Federal Standard 406 Method 2021
Acrylic (Stretched)	MIL-P-25690	Burning	1. 0-1. 5	Federal Standard 406 Method 2021

CONCLUSIONS AND RECOMMENDATIONS

GENERAL

The collection of data and the subsequent analysis resulted in the following conclusions and recommendations.

CONCLUSIONS

1. The properties most commonly used in design have been widely tested and test values documented for all the currently used transparency materials. The most recent contribution was a program funded by the Air Force to perform tests on polycarbonate and reported in Technical Report AFML-TR-72-117. However, the number of tests of any specific material, material property, and test condition are limited, and the test results are most commonly reported only as "average values" or as "typical properties." As a result, there are no data which can be construed as "design values" comparable to the value published in MIL-HDBK-5 for the most commonly used metals. As a result, designers are forced to use the "typical values" and put on them what is hoped to be a very conservative factor to obtain values they use in analysis.

2. Polycarbonate, the newest material, has been successfully used in some helicopter transparencies. Most applications have been in noncritical optical areas and locations with minimum probability of service damage such as side windows and skylights. There is one instance of a windshield application, however, and there were no unusual complaints of optical quality from operational pilots or surface degradation from service and maintenance. There were reports of efforts to fabricate other windshield panels, but acceptable contours had not been achieved.

3. The reported advantages of polycarbonate over stretched acrylic were:

   a. Total elimination of backside spall from gunfire along with very small, nearly self-healing holes

   b. Replacement involving drilling out rivets and reriveting, resulting in fewer cracked windows

4. The problems with using polycarbonate compared to stretched acrylic are:

   a. Limitations of contour which can be successfully formed similar to those of as-cast acrylic

   b. Formed parts have more optical distortions. NOTE: This is readily apparent in the one windshield application in which both have been used which made possible a direct comparison. The operational pilots do not notice the difference, however, so that it in no way impairs the function of the helicopter in that particular application

   c. Polycarbonate is more subject to attack from many common fluids and to abrasion from undisciplined cleaning, etc. NOTE: This was significant in only one of the windshield panels. In that case the polycarbonate panel was destroyed by exposure to gasoline.

5. In general, polycarbonate has a definite future as a helicopter glazing material primarily because of its excellent shatter resistance and good impact strength. It does have peculiar problems, however, which must be recognized, and provided for, in design. Its increased temperature resistance as compared to stretched acrylic would not appear to be a factor in helicopter design.

6. The use of windshield wipers on the surface of any currently existing transparent material other than inorganic glass will cause wear of the surface which should receive greater attention in design than it has received in the past. The investigation suggests the possibility of at least three different approaches to solution:

   a. Replace the windows with glass or laminate glass to the surfaces. Penalties will be paid in weight, initial and replacement cost, shatter resistance, and formability.

   b. Reevaluate the need for windshield wipers. There were many instances in which the wipers were made inoperative without apparent compromise to the vehicle's utility.

c. Establish a design with the plastic material, with or without abrasion-resistant coating, which MTBF and cost trade-off studies determine to be most advantageous; design for convenient transparency replacement; and establish set intervals at which the transparencies are to be replaced.

7. The absence of an effective and accepted standard method to objectively evaluate distortions and deviations of transparencies results in wide variations in levels of optical quality considered to be satisfactory. The objective methods of inspection currently specified are so lightly regarded that many times they are ignored in favor of subjective evaluation by the inspector. The practice of this philosophy may create problems of procurement, levels of optical quality greater than necessary for some application, and may generate items of cost which do not contribute to the function of the transparency.

8. During the study program, the absence of complaints from the pilots of optical problems relating to new transparencies indicates that even the lowest current acceptance level for optical quality fulfills the functional requirements. This absence of complaint was maintained in the face of direct questioning and pointing out of examples for comment. It is therefore concluded that the most liberal optical standard currently being used is adequate for helicopter glazings.

9. The accuracy of all the maintenance record computer data is primarily contingent upon the originator of the failure report and the selection of the failure code from the description list.

   The similarity and a lack of precise definition of terms peculiar to transparencies and optical practices have led to erroneous analyses of maintenance records. An example of this situation is the synonymous use of the words scratch and distortion.

   Another source of error was the use of the same FSN for alternate types of windshields used on the same helicopters. This situation obviously leads to inaccurate failure analyses.

10. The military personnel who have attended the applicable maintenance and repair schools were surprisingly knowledgeable and conversant with helicopter transparencies. Many personnel came in direct contact with military helicopter transparencies. The majority of

these personnel have not had the advantages of the military maintenance and repair schooling. The plastic transparencies therefore suffer severe degradation from solvents, vapors, and abrasive materials. This degradation is attributable to a lack of knowledge on the part of personnel not necessarily directly associated or trained in the handling or maintenance of plastic transparencies.

11. One commercial helicopter operator who operated a fleet in excess of two hundred helicopters was the subject of a survey during the study program. The transparencies on the commercial fleet were somewhat superior, in general appearance, to their counterpart in the military fleet. This superior appearance was attributable to several conditions. Two conditions that were credited by the mangement for superior appearance was the educational process of all associated personnel including pilots and passengers. There was also a general usage of decals apprising personnel of the limitations of plastic transparencies. Incorporation of these concepts by the Army should result in greater appreciation of the fragility of transparencies and extend their service life.

12. Heated transparencies (laminated) have a notoriously short life span. The computer failure mode data for one specific helicopter showed that in excess of one-third of all failures requiring replacement were attributable to delamination. The mean time between failures for these windshields was computed at 259.5 hours. The reliability analysis by the prime contractor stated that due to the poor reliability and high cost of the windshield assemblies, aircraft are flying with window assemblies in a degraded state that should be replaced. There has been no attempt to adjust the MTBF to reflect this condition. During the data collection period of the study program, it was observed on several occasions that delaminated windshields were in aircraft that were still on a flying status.

13. Glare and reflections from windshields were reported as a problem area. There are continuing active programs in which antiglare film is being used. The purpose of these programs is to determine if visual detection from reflections can be reduced. The study revealed no existing solution to this problem. It is readily apparent that this need is well recognized.

The other facet of reflection is the pilot complaint of reflections in the cockpit, particularly during night operations.

In one specific helicopter configuration, it was reported that in flying at night over ground lights it was common to pick up a light source from the ground through the chin bubble and the light in turn being reflected off the windshield into the pilot's eyes. This reflected light gave the pilot the illusion of a light source being directly ahead of the helicopter.

Anti-reflective coatings are available. Certain applications are very common, such as on camera lenses. Application techniques and resistance to erosion as applicable to the large helicopter windshields present a need for development.

RECOMMENDATIONS

1. It is recommended that adequate tests be performed to establish real design allowables for a limited number of properties of aircraft glazing materials.

   The design allowables could be established for tensile ultimate, tensile modulus compressive ultimate, and compressive modulus at room temperature, 180°F and -65°F. The shear strength in the plane of the surface and the shear strength normal to the plane of the surface should be established.

2. The initiation of a polycarbonate improvement program should receive high priority, in that polycarbonate has shown some highly desirable properties. The improvement program should be divided into two separate areas of endeavor. The areas of development for improving the known deficiencies are:

   a. Improved processes for reworking surfaces to increase optical performance

   b. Improved surface coatings for abrasion and solvent resistance

3. The establishment of a standard method for objectively evaluating distortion and deviation in transparencies is needed. It is recommended that the various techniques currently in use for measuring optical distortion be evaluated to eliminate the subjective evaluations of transparencies which are commonplace today. Finite values and accepted processing techniques must be recognized.

GLOSSARY

1. Haze. Haze is that percentage of transmitted light that in passing through the specimen deviates from the incident beam by forward scattering. For the purpose of this report, only light flux deviating more than 2.5 degrees on the average is considered to be haze. (See luminous transmittance.) (Reference: Federal Test Method Standard No. 406, paragraph 5.29.)

2. Luminous transmittance. Luminous transmittance is the ratio of transmitted to incident light. (See haze.) (Reference: Federal Test Method Standard No. 406, paragraph 5.32.)

3. Deviation. The displacement of a beam of light as a result of its passing through a transparency at an angle; this is a function of the angle of incidence at each thickness of material and index of refraction of the material.

4. Angular deviation (optical). The angular change in direction of a light ray when the light ray is refracted by passing through a transparent medium of a different density than that of air.

5. Optical distortion. The rate of change of angular deviation. This manifests itself by causing apparent twisting or misshaping of an object when it is viewed through an imperfect transparency.

6. Mark-off. The surface finish of an optical transparency picked up by the transparency as a result of contacting the forming mold surface during the forming process.

7. Crazing. Fine cracks which may extend in a network over or under the surface or through a plastic. These cracks gradually enlarge with continued application of load.

APPENDIX I
HELICOPTER TRANSPARENCY FAILURE DATA

GENERAL

As a part of the data collection survey of the subject contract, various Government and commercial sources were contacted for existing specific information describing the transparency construction and configuration plus historical information relating to the service performance of the specific transparencies. Specifications used for procurement, qualification, and acceptance testing of the transparencies were also sought. All major helicopter manufacturers were contacted by personal visits to request the specific information. Besides the manufacturers, a second source of specific information, especially regarding field service experience, was the U.S. Army Aviation Systems Command (AVSCOM) at St. Louis. This facility is the worldwide data bank for all the maintenance records for Army aircraft. All data is stored on computer tapes, and various programs are used to extract various pieces of information from the tape.

In addition to the specific information requested from the above sources, certain subjective data was also gathered from a number of sources, primarily pilots and maintenance personnel at various Army, Marine Corps, Air Force, Navy, and civilian facilities operating and/or maintaining helicopters. The information was gathered by personal interviews with the personnel involved at each facility. The subjective data received during these interviews is contained in the text of this report.

Table VIII summarizes the information source and type of information received from each during the survey.

MAINTENANCE AND FAILURE INFORMATION FROM DATA SURVEY

General

As shown in Table VIII, field service data was not available for all helicopters in Army service. However, it is believed that the data obtained is representative of all types of transparencies, helicopter types, and service conditions experienced during normal operations. The shortest sample period for which data was obtained was 6 months for the AH-1G. However, two separate 6-month surveys were available for this helicopter, and one was known to have covered 95,476 flying hours for a total fleet size of approximately 600 aircraft. Other surveys covered at least a 12-month period of helicopter operation.

TABLE VIII. DATA SURVEY RESULTS

Source and Helicopter Designation	Information Received			
	Drawings	Specifications	Field Service Data	Subjective Data
Bell Helicopter				
TH-13, OH-13	-	-	-	-
UH-1B, C	x	x	x	-
UH-1D, H	x	x	x	-
AH-1G	x	-	-	-
OH-58A (TH-57)	x	x	x	-
Hughes Aircraft				
TH-55A	-	x	-	-
OH-6A	x	x	-	-
Kaman Aerospace				
H-2	x	x	x	-
HH-43	x	-	-	-
Sikorsky Aircraft				
CH-54	x	-	x	-
CH-53	x	-	x	-
H-3	x	-	x	-
CH-34*	-	-	-	-
CH-37	-	-	-	-
Vertol Division, Boeing				
CH-46	x	x	-	-
CH-47	x	x	x	-
U. S. Army Aviation Systems Command				
AH-1G	-	-	x	-
CH-47A	-	-	x	-
CH-54A	-	-	x	-
OH-58A	-	-	x	-
UH-1	-	-	x	-

*No longer in Army service.

TABLE VIII - Continued				
	Information Received			
Source and Helicopter Designation	Drawings	Specifications	Field Service Data	Subjective Data
U. S. Army Transportation Center, Ft Eustis				
UH-1	-	-	-	x
OH-58	-	-	-	x
CH-47	-	-	-	x
OH-6	-	-	-	x
OH-13	-	-	-	x
AH-1	-	-	-	x
U. S. Army Aviation Center Procurement Division, Ft. Rucker				
TH-13	-	-	-	x
UH-1	-	-	-	x
OH-58	-	-	-	x
OH-6	-	-	-	x
CH-47	-	-	-	x
CH-54	-	-	-	x
AH-1	-	-	-	x
U. S. Army Primary Helicopter School, Ft. Wolters				
TH-13	-	-	-	x
TH-55	-	-	-	x
OH-58	-	-	-	x
Fort Hood, Texas				
UH-1	-	-	-	x
AH-1	-	-	-	x
OH-58	-	-	-	x

TABLE VIII - Continued				
	Information Received			
Source and Helicopter Designation	Drawings	Specifications	Field Service Data	Subjective Data
Army Aeronautical Depot Maintenance Center, Corpus Christi				
UH-1	-	-	-	x
AH-1	-	-	-	x
Santa Ana Marine Base, California				
CH-46	-	-	-	x
CH-53	-	-	-	x
El Toro Marine Base, California				
CH-46	-	-	-	x
CH-53	-	-	-	x
Hill AFB, Utah				
H-53	-	-	-	x
H-3	-	-	-	x
UH-1	-	-	-	x
355th Aviation Company, Ft. Eustis				
CH-54	-	-	-	x
Petroleum Helicopter, Lafayette, Louisiana				
Bell Model 206B (OH-58)	-	-	-	x
Hughes Model 500 (OH-6)	-	-	-	x
Ellyson Field, Pensacola, Florida				
Navy H-57 (OH-58)	-	-	-	x

The results of all the maintenance action surveys are summarized in Tables IX through XIX. Each table shows the results of one or more data surveys for a particular helicopter from a particular source. The individual transparencies are listed and the number of maintenance actions reported for each transparency by failure code are tabulated. Where known, the number of transparencies replaced and the number repaired are also recorded along with the total number of man-hours reported to replace or repair the transparencies listed. The failure codes are the standard codes used by the Army Maintenance Management System (TAMMS) and the equivalent Navy 3M system.

Table XX is the list of failure codes provided in TM 38-750, "The Army Maintenance Management System." However, a larger, more comprehensive list of failure codes is also available to the service personnel preparing the maintenance action forms. Many of the failure descriptions grouped under one code in Table XX are given separate failure codes in the comprehensive listing. For example, separate failure codes exist for cracked, cut, torn, and punctured. Unfortunately, when a failure code such as 070 is listed, it is not possible in all cases to determine if the failure is specifically a broken failure or if it is a cracked, cut, or torn failure. In all cases, the tables herein use the failure codes as designated in the data source.

To aid the reader in identifying the transparencies, sketches are included for each helicopter model to show the transparency location, its thickness, and the type of material used as identified by the military specification (see Figures 1 through 8).

H-3 Helicopter

No specific tabular data was received on the H-3 helicopter. However, the following data is quoted from a letter from Sikorsky Aircraft and was furnished in reply to a request for data from Goodyear Aerospace (see Figure 9 for H-3 windshield configuration).

"Reliability data for the H-3 (S-61) model helicopter is based primarily on Sikorsky Aircraft's data collection system. Windshields from several vendors composed of various materials both heated and unheated, have been installed in the H-3. The work unit code, reference MIL-STD-780C, makes no provision for this, therefore data, fed back through the 3M system, is not reliable.

"No problems have been experienced attributable to quality or serviceability of transparency materials in any of the H-3 models except for those used in windshield installations. The numerous cases of lost or broken cabin and cockpit windows have resulted from retention structure inadequacies or maintenance and service induced discrepancies. They are thus not pertinent to the materials reliability study contract.

TABLE IX. AH-1 TRANSPARENCY MAINTENANCE ACTION (JULY 1, 1970 TO DECEMBER 31, 1970)

Item	Failure Code										Summary			
	020 Worn Excessively	027 Collapsed Buckled	070 Broken	190 Cracked	713 Battle Damage	750 Missing	910 Chipped	717 Accident Damage	730 Loose	799 No Defect	Number Replaced	Man-Hours to Replace	Number Repaired	Man-Hours to Repair
Pilot Window, LH														
209-030-507-3	-	-	6	-	-	1	3	-	-	-	9	303.0	1	40.0
-45	-	-	-	-	1	-	1	-	-	-	2	39.0	0	-
Gunner Window, RH														
209-030-508-3	-	1	9	-	3	-	3	1	2	-	15	320.0	4	31.0
-39	-	-	-	-	-	-	1	-	-	-	1	30.0	0	-
Gunner Door Assembly, LH														
209-030-515-3	-	-	1	-	1	-	1	-	-	1	3	24.5	1	3.0
-49	1	-	1	-	-	-	-	-	-	-	1	36.0	1	0.6
Pilot Door Assembly, RH														
209-030-516-3	-	-	-	1	1	-	-	-	-	1	3	34.5	-	-
-51	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cabin Center Window														
209-030-509-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Totals	1	1	17	1	6	1	9	1	2	2	34	787.0	7	74.6

Source: AVSCOM Special extract of RAMMIT Maintenance Action Files, Project FG2AJB

TABLE X. AH-1G TRANSPARENCY MAINTENANCE ACTIONS

Item	Failure Code													Summary			
	031 Alignment	020 Worn Excessively	127 Adjustment Improper	070 Broken	190 Cracked	381 Leaking	520 Pitted	713 Battle Damage	730 Loose	750 Missing	799 No Defect	910 Chipped	Other	Number Replaced	Man-Hours to Replace	Number Repaired	Man-Hours to Repair
Pilots Window Assembly	-	-	-	2	-	1	-	2	-	-	-	-	-	2	11.0	3	3.0
Pilot Door Assembly	1	1	12	40	3	-	-	-	4	2	8	2	9	45	625.5	37	94.0
Gunner Door Window	-	-	-	2	-	-	-	1	-	-	-	2	-	4	46.0	1	3.0
Gunner Door Assembly	2	1	11	21	-	-	-	-	1	2	1	-	6	22	394.3	23	78.7
Window	-	1	-	5	-	-	-	-	-	-	-	-	-	4	199.0	2	5.5
Canopy Assembly Installation	-	-	2	10	-	2	1	4	-	-	-	1	2	12	241.5	10	69.7
Window Assembly	-	-	-	35	-	-	-	7	3	-	-	14	10	56	1862.6	13	93.3
Totals	3	3	25	115	3	3	1	14	8	4	9	19	27	145	3379.9	89	347.2

Source: AVSCOM Maintenance Action Summary, Project FG2BWF-04. Fleet size approximately 600 aircraft, 6 months data, 95,476 flying hours

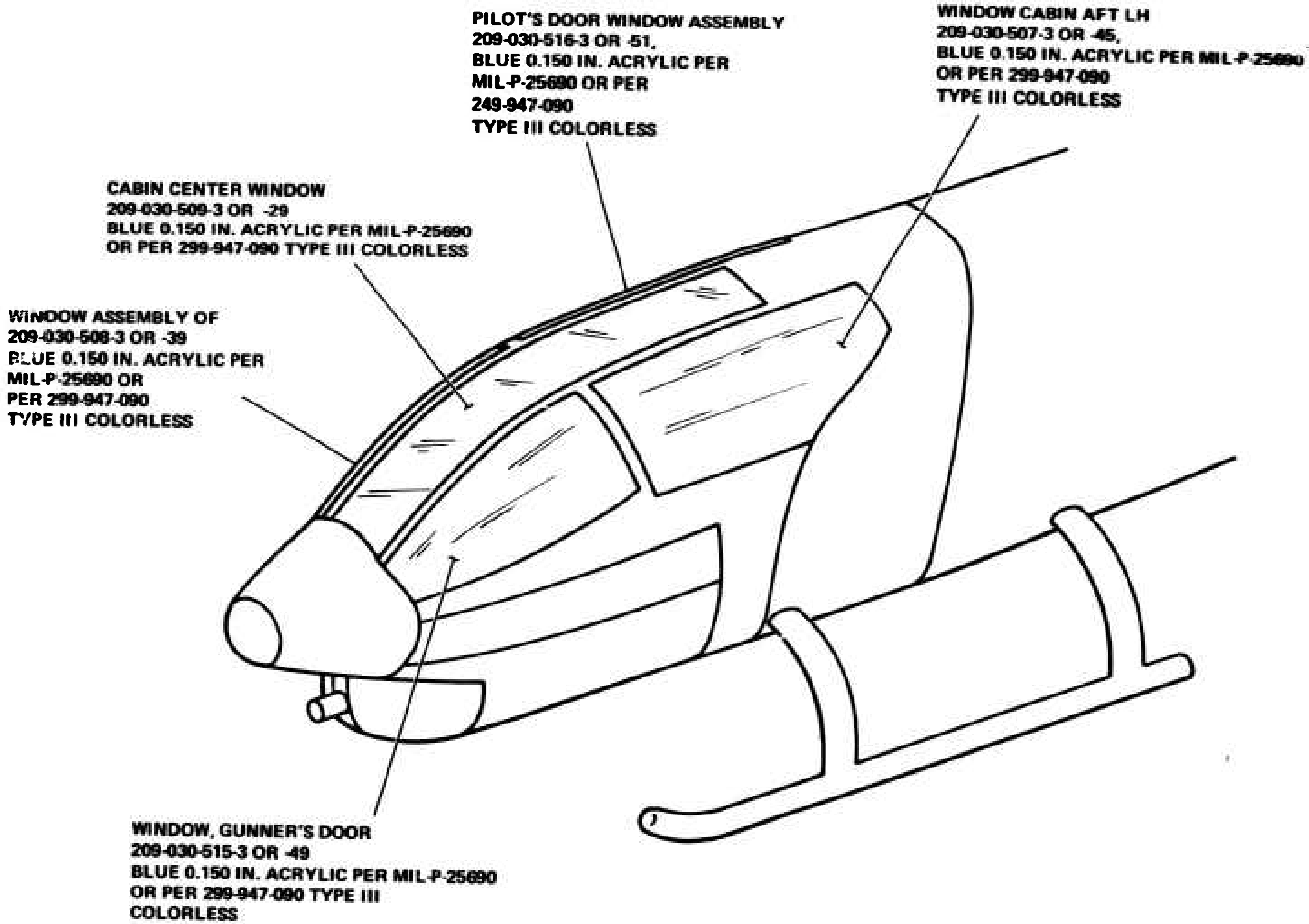


Figure 1. AH-1 Transparencies.

TABLE XI. MODEL CH-47A TRANSPARENCY MAINTENANCE ACTIONS FOR FY 1970

Item	Failure Code											
	020 Worn Excessively	050 Blistered	070 Broken	190 Cracked	230 Dirty	607 Distortion	846 Delaminated	900 Burned	910 Chipped	920 Not Determined	935 Scored	Total
Windshield 114SS604-1 -2	4	1	15	5	-	-	-	13	21	2	3	64
Intermediate Windshield 114SS602-4	1	-	15	2	-	1	1	5	4	1	-	30
Nose Bubble 114S1715-35 -36	-	-	6	-	-	-	-	-	2	-	-	8
Crown Pane 114S1714-29 -30	-	-	8	2	1	-	-	1	1	1	-	14
Sliding Pane	3	-	3	1	-	-	-	1	-	-	-	8
Sliding Window	-	-	1	1	-	-	-	-	-	1	-	3
Totals	8	1	48	11	1	1	1	20	28	5	3	129

Source: AVSCOM Special Extract of RAMMIT Maintenance Action files, Project FG2AJB

TABLE XII. CH-47 TRANSPARENCY MAINTENANCE ACTIONS

Item	Time Period	Flight Hours	Failure Codes: 068 Heater Inoperative	070 Broken	127 Out of Adjustment	135 Binding	190 Cracked	196 Shorted	381 Leaking	490 Scratched	607 Distorted	730 Loose	750 Missing	846 Separated	Other	Primary failures: Number of Occurrences	Primary failures: Man-Hours	Nonprimary failures or maintenance actions: Number of Occurrences	Nonprimary: Man-Hours
Windshield and windshield Assemblies (except 114S1607-103 and -104 and 114S1647-3 and -4)	July 1965 to February 1967	6837	-	-	4	3	7	-	17	12	-	-	-	-	2	36	82.2	9	9.2
Door Assembly, Cockpit Jettisonable Sliding Window 114S1607-103, -104	July 1965 to February 1967	6837	-	-	-	3	-	-	-	-	-	1	-	-	-	3	2.0	1	1.0
Door Assembly, Cockpit Jettisonable Sliding Window 114S1647-3, -4	July 1965 to February 1967	6837	-	-	4	-	-	-	-	-	-	1	-	-	2	5	3.7	2	0.5
Windshield 114SS601-7, -8	July 1967 to April 1968	1788.5	-	1	-	-	1	-	1	-	-	-	-	-	-	3	5.5	0	0
Crown Pane Assembly 114S1714-2	July 1967 to April 1968	1788.5	-	-	-	-	1	-	-	-	-	-	-	-	-	1	16.5	0	0
Windshield 114SS601-7, -8	April 1968 to June 1969	4974.8	1	-	-	-	3	-	1	6	-	-	-	2	1	12	36.8	2	4.7
Windshield, Intermediate 114SS602-4	April 1968 to June 1969	4974.8	1	-	-	-	-	1	-	-	-	-	-	-	1	2	6.5	1	1.0
Pane, Cabin Window 114S2721-5	April 1968 to June 1969	4974.8	-	-	-	-	-	-	-	-	-	-	3	-	-	0	0	3	4.5
Crown Pane Assembly 114S1714-30	April 1968 to June 1969	4974.8	-	-	-	-	1	-	1	-	-	-	-	-	-	1	0.5	1	0.2
Windshield 114SS604-1, -2	June 1969 to September 1970	4132.2	-	-	-	-	1	-	1	-	-	-	-	-	-	3	12.17	16	63.51
Windshield, Intermediate 114SS602-4	June 1969 to September 1970	4132.2	1	-	-	-	-	-	1	-	-	-	-	1	-	1	4.0	2	0.42
Crown Pane Assembly 114S1714-29, -30	June 1969 to September 1970	4132.2	-	-	-	-	-	-	4	-	-	-	-	-	-	0	0	4	1.80
Window Assembly, Sliding 114S1649-5, -6	June 1969 to September 1970	4132.2	-	-	10	-	-	-	-	-	-	3	-	-	1	0	0	14	5.48
Pane, Cabin Window 114S2721-5	June 1969 to September 1970	4132.2	-	-	-	-	-	-	-	-	-	11	8	-	-	0	0	19	5.47
Pane Assembly, Nose Bubble 114S1715-35, -36	June 1969 to September 1970	4132.2	-	-	-	-	-	-	-	-	-	-	-	1	-	1	2.50	0	0
			3	1	18	6	13	1	36	26	2	18	11	5	7	73	172.37	74	100.77

Source: The Boeing Company

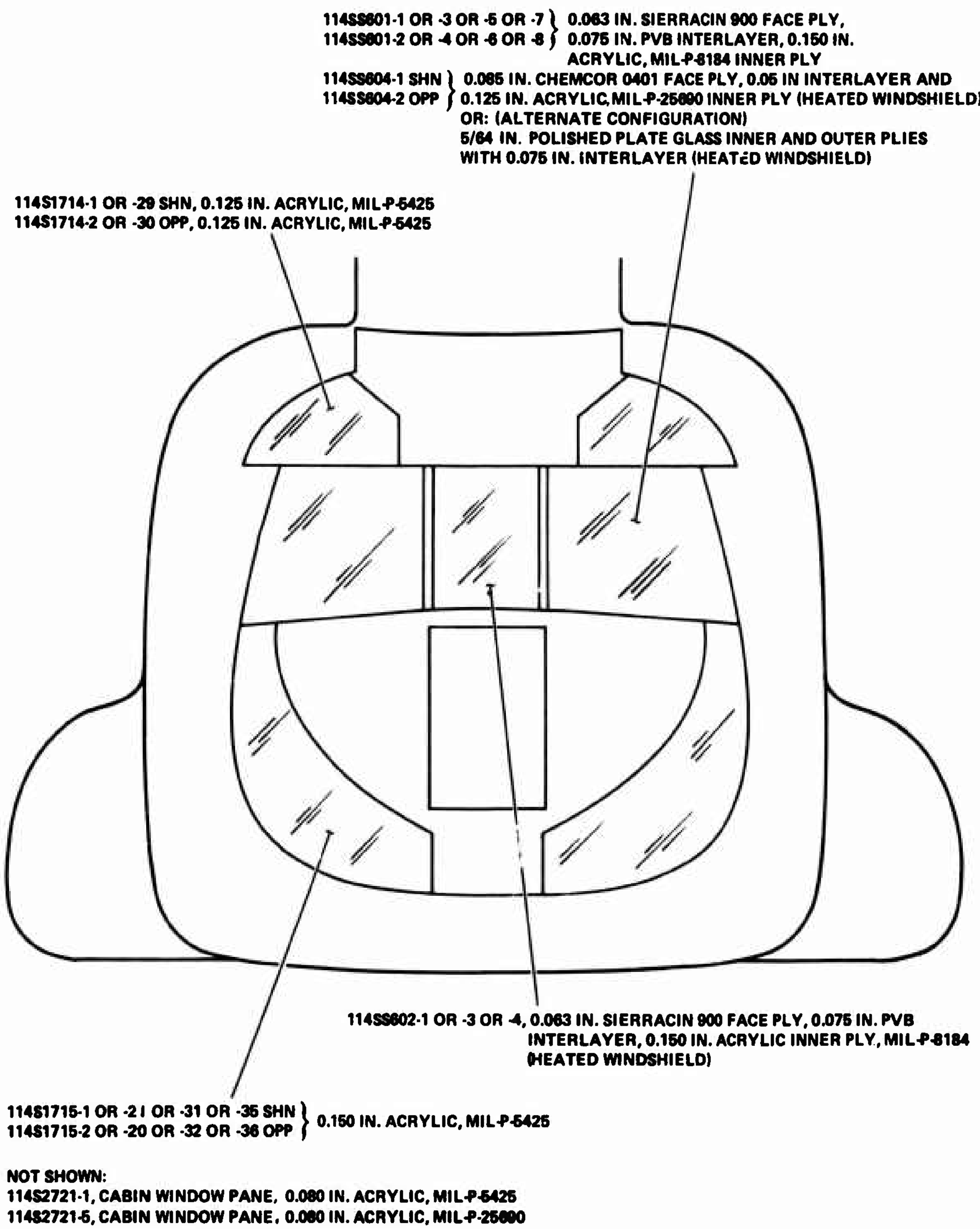


Figure 2. CH-47 Transparencies.

TABLE XIII. CH-54A TRANSPARENCY MAINTENANCE ACTIONS FOR FY 1971

Item	Failure Code				Summary			
	070 Broken	170 Corroded	713 Battle Damage	750 Missing	Number Replaced	Man-Hours to Replace	Number Repaired	Man-Hours to Repair
Windshield, BL 0 6420-61328-101	3	-	-	-	3	21.8	-	-
Windshield, Side 6420-61356-101	-	-	-	-	-	-	-	-
Lower Bubble 6420-61332-103 -104	-	-	-	-	-	-	-	-
Corner Windshield 6420-61330-104	3	-	-	-	3	16.0	-	-
Eyebrow Window 6420-61333-101 -102 -103 -104	-	-	-	-	-	-	-	-
Side Cockpit Door Assembly 6420-61145	-	-	-	-	-	-	-	-
Personnel Door Installation 6420-61706-106 -107	-	-	-	-	-	-	-	-
Panel Installation, Station 160 6420-61707-107	1	1	-	1	3	4.8	-	-
Rear Enclosure Installation 6420-61705-104	-	2	1	-	3	35.3	-	-
Totals	7	3	1	1	12	77.9	-	-

Source: AVSCOM Special Extract of RAMMIT Maintenance Action Files

TABLE XIV. CH-54 TRANSPARENCY FAILURE DATA

Item	Failure Mode 190 Cracked	070 Broken	607 Distorted	386 Lost in Flight	854 Hazy	520 Pitted	Totals
Door Assembly, Side Cockpit, Window LH 6420-61145-223	7	1	-	-	-	-	8
Door Assembly Window, RH 6420-61145-224	7	1	-	-	-	-	8
Door Assembly Window, LH 6420-61145-170	2	-	-	-	-	-	2
Door Assembly Window, RH 6420-61145-226	3	-	-	1	-	-	4
Enclosure Installation Station 136-160 LH 6420-61705-101	1	-	-	-	1	-	2
Door Installation, RH Side, Personnel 6420-61706-106	-	-	-	2	-	-	2
Window Installation Cockpit Canopy, LH 6420-61332-101	1	-	-	-	-	-	1
Window Installation Cockpit Canopy, LH 6420-61332-103	-	1	1	-	-	-	2
Windshield, Center 6420-61328-101	1	-	-	-	-	-	1
Windshield, Center 6420-61328-102	2	-	-	-	-	-	2
Windshield, LH 6420-61356-101	4	-	-	-	-	2	6
Totals	28	3	1	3	1	2	38

Source: Sikorsky Aircraft letter SSD 64N21C. 2, Enclosure 3. Data covers approximately 48, 000 flight hours.

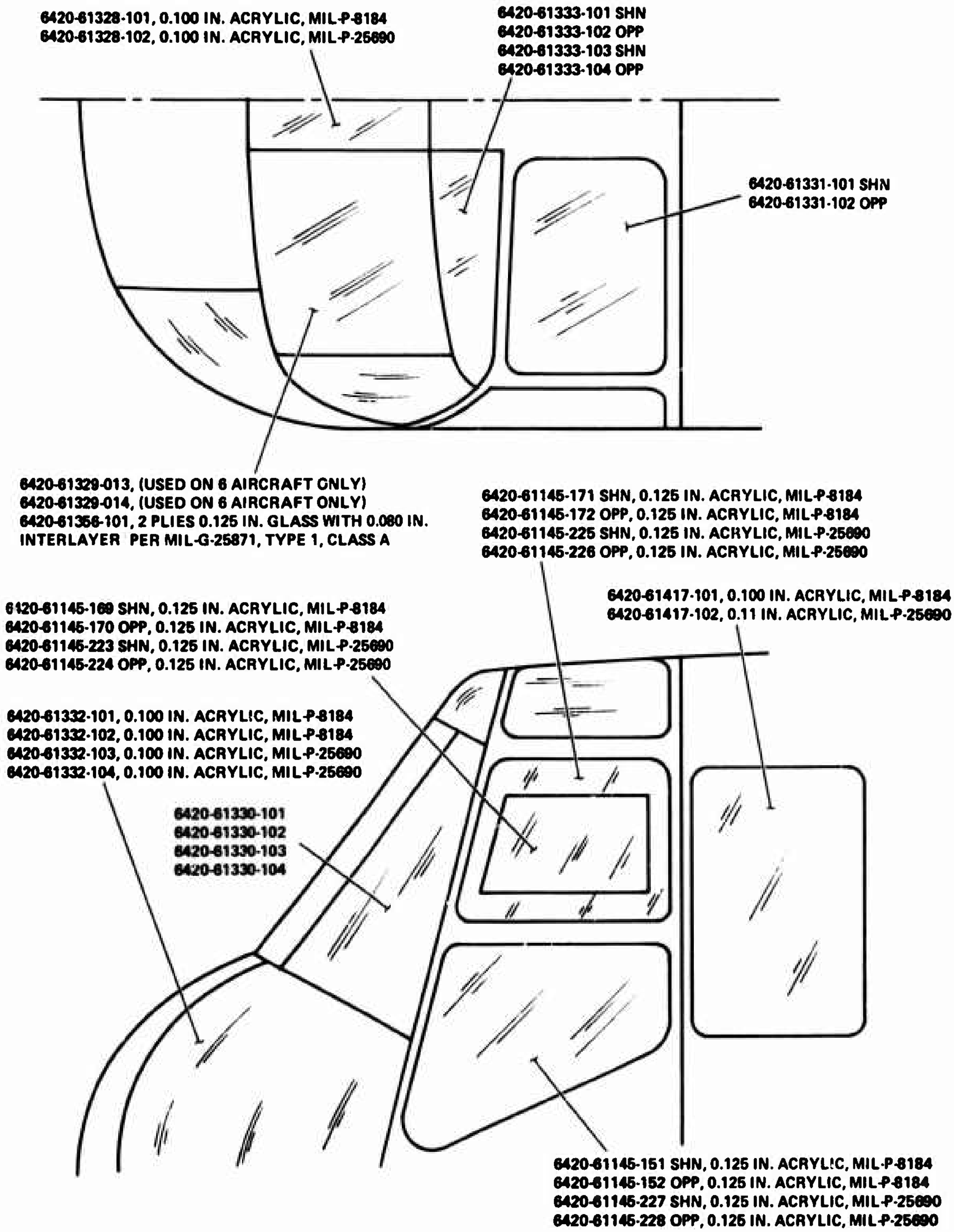


Figure 3. CH-54 Transparencies.

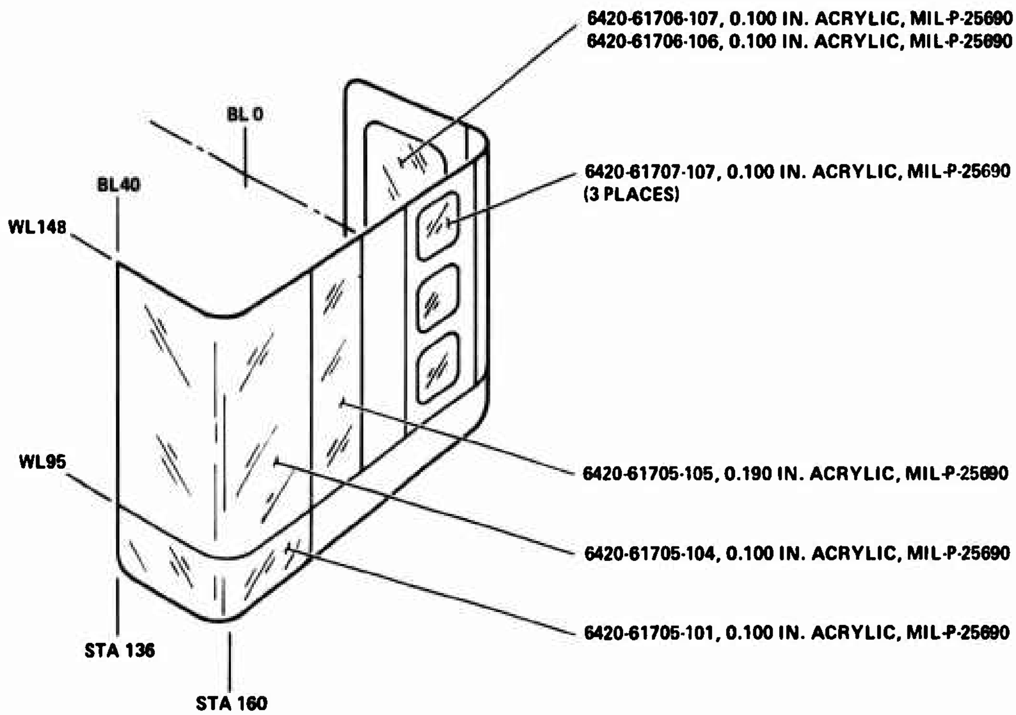


Figure 4. CH-54 Rear Enclosure Transparencies.

TABLE XV. UH-1 TRANSPARENCY FAILURE SUMMARY

Item	070 or 190 Broken or Cracked	490 Scratched	713 Battle Damage	717 Accident	841 Abraded	Total
Windshield 204-030-666-031 -032	6	79	15	3	-	103
Windshield 204-030-666-043 -04[illegible]	1	62	2	-	-	65
Lower Forward Window 204-030-657-19 -20	49	-	16	-	-	65
Cabin Window 204-031-669-007	9	-	4	4	-	17
Panel Window 204-030-285-001 -002	3	-	-	29	-	32
Forward Door Window 204-030-459-001 -002	4	-	7	-	-	11
Door Window 204-030-799-1	46	-	21	-	4	71
Door Upper Window 204-030-770-001 -002	5	-	5	-	-	10
Totals	123	141	70	36	4	374

Source: Bell Helicopter Company, M and R Program, Field Failure/ Discrepancy Report Listing, Dated 9 August 1972

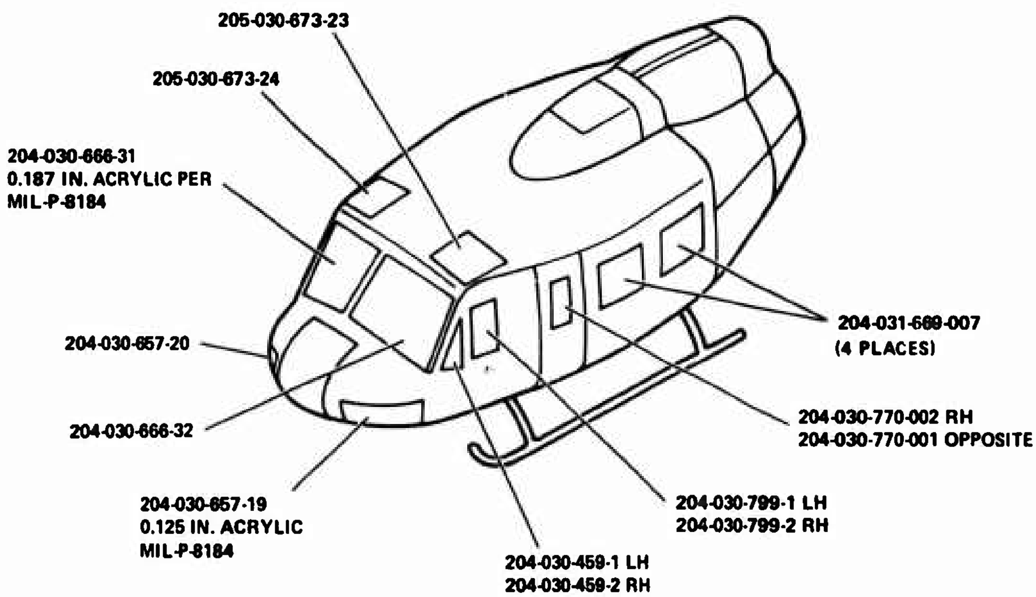


Figure 5. UH-1 Transparencies.

TABLE XVI. MODEL OH-58A TRANSPARENCY MAINTENANCE ACTIONS FOR JANUARY 1, 1970 TO JUNE 30, 1970

	Failure Code										Summary			
Item	020 Worn Excessively	070 Broken	190 Cracked	230 Dirty	381 Leaking	713 Battle Damage	717 Accident Damage	750 Missing	027 Collapsed	540 Punctured	Number Replaced	Man-Hours to Replace	Number Repaired	Man-Hours to Repair
Windshield 206-032-115-15 -16	1	6	3	3	1	1	1	-	-	1	11	387.5	6	25.0
Crew Door Window 206-032-500-19 -20	-	10	-	-	-	-	-	1	-	-	9	115.2	2	3.5
Passenger Door Window 206-032-501-19 -20	-	5	4	-	-	-	-	-	-	-	6	59.5	3	7.0
Lower Window 206-032-116-15 -17	-	13	-	2	-	2	1	-	1	-	14	164.5	5	34.0
Skylight 206-031-108-19 -20 -25 -26	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Totals	1	34	7	5	1	3	2	1	1	1	40	726.7	16	69.5

Source: AVSCOM special extract of RAMMIT Maintenance Action files. Project FG2AJB

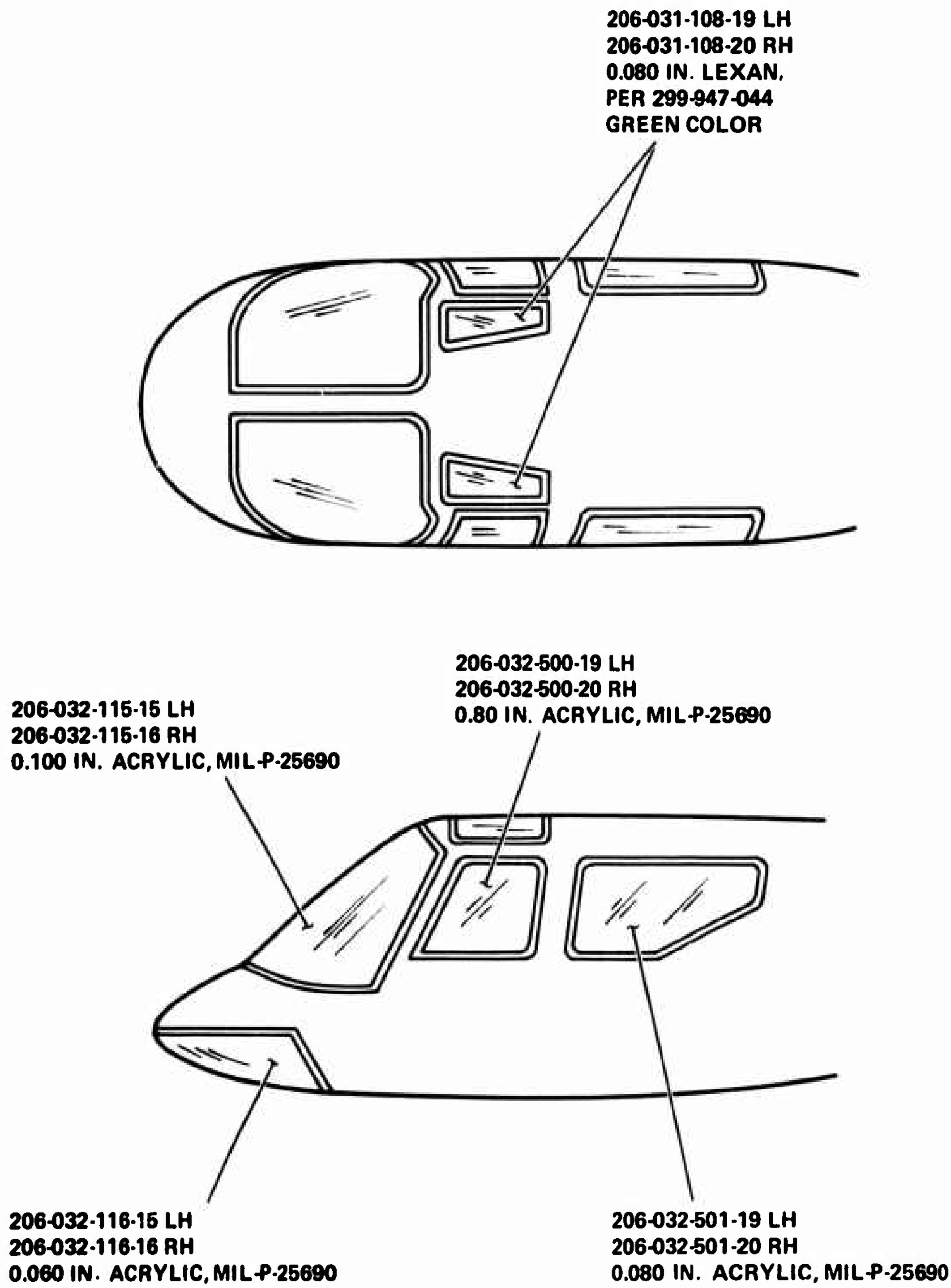


Figure 6. OH-58A Transparencies.

TABLE XVII. CH-53 TRANSPARENCY MAINTENANCE ACTIONS

Item	Failure Code												
	846 Delaminated	935 Scored	Crazed	070 Broken	190 Cracked	607 Distorted	135 Binding	900 Burned	117 Deteriorated	106 Missing Hardware	386 Lost in Flight	093 Missing Part	Totals
Windshield, LH 65206-01003-109	23	14	20	2	4	1	1	-	-	-	-	-	65
Windshield, RH 65206-01003-110	21	12	14	1	10	5	-	1	1	-	-	-	65
Windshield, Center 65206-01009-105	36	8	15	1	4	5	-	2	-	-	-	-	71
Overhead Window, LH 65206-01004-101	-	1	1	1	-	2	-	-	-	-	-	-	5
Overhead Window, RH	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Glass, RH 65206-01006-102	-	1	-	-	-	-	-	-	-	-	-	-	1
Bottom Glass, LH 65206-01007-101	-	1	-	1	1	1	-	-	-	-	-	-	4
Bottom Glass, RH 65206-01007-102	-	1	-	-	-	-	-	-	-	-	-	-	1
Cabin Windows 65206-05003	-	-	-	7	6	1	-	-	1	5	7	2	29
Personnel Door Window 65207-03035-081	-	-	-	1	-	-	-	-	-	-	-	-	1
Forward Cabin Escape Window 65207-03039-081	-	-	-	3	1	-	-	-	-	-	-	-	4
Window Rear Door Escape 65207-10028-041	-	-	-	4	2	1	-	-	-	-	-	1	8
Totals	80	38	50	21	28	16	1	3	2	5	7	3	254

Source: Sikorsky Aircraft, 3M data extract, April 1970 to December 1971, 52,154 flight hours

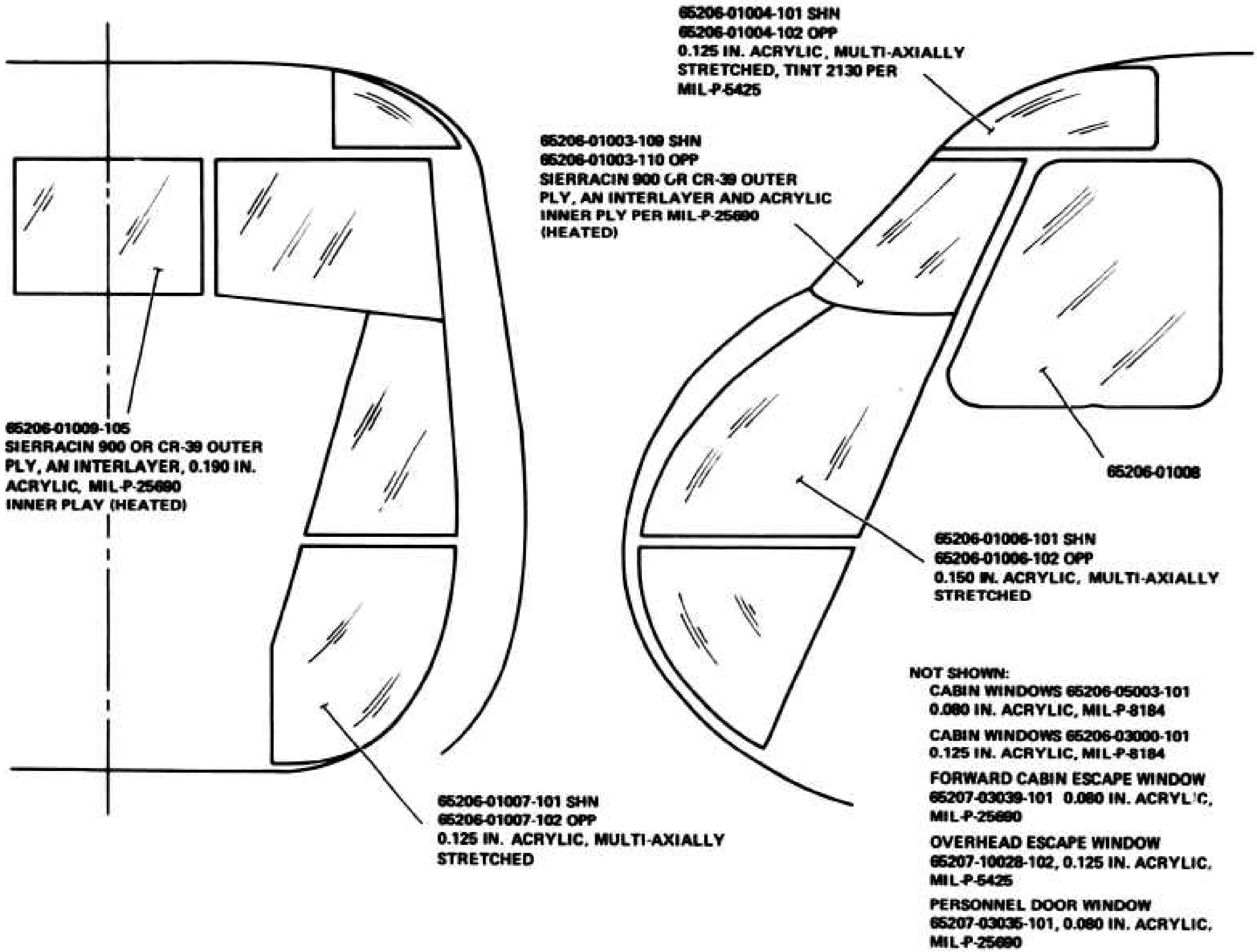
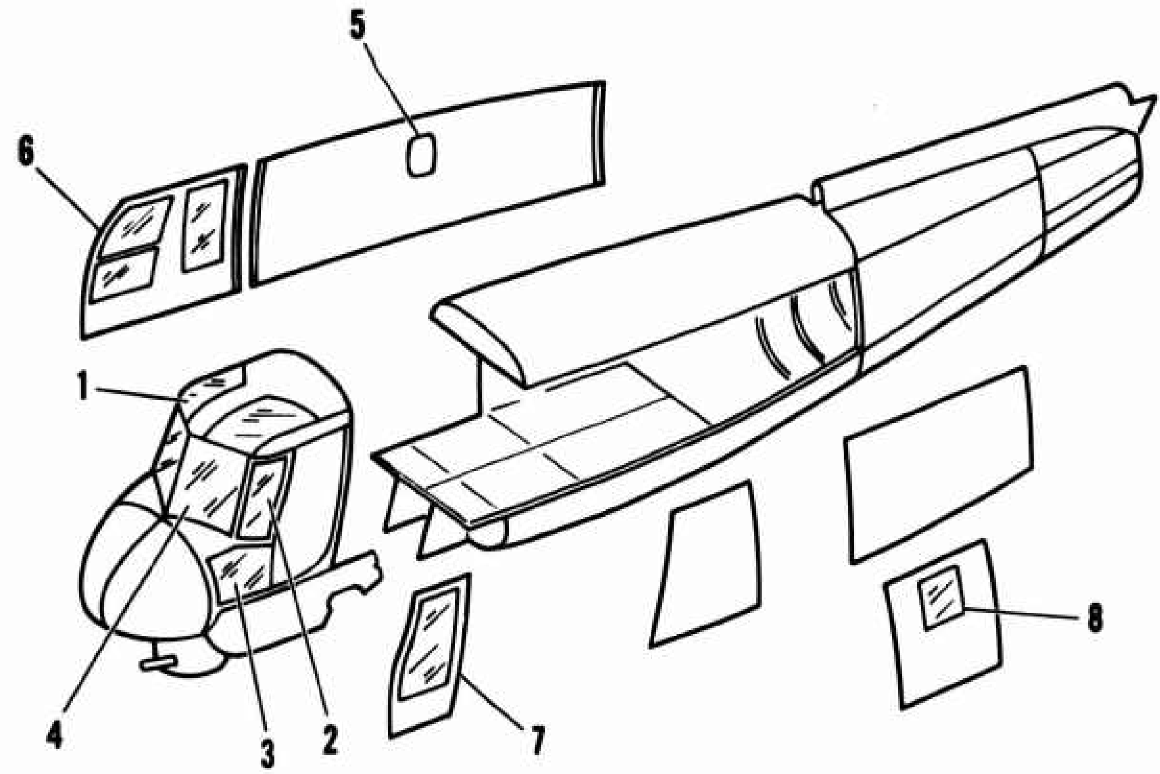


Figure 7. CH-53 Transparencies.

TABLE XVIII. H-2 TRANSPARENCY MAINTENANCE ACTIONS FOR YEAR ENDING DECEMBER 1971

Item	Replacements		Repairs		Failure Modes												
	Occur- rences	Man-Hours	Occur- rences	Man-Hours	381 Leaking	070 Broken	190 Cracked	105 Loose	Deteri- orated	170 Corroded	116 Cut	520 Pitted	106 Loose or Missing Hardware	020 Worn Chafed, Frayed	246 Faulty Main- tenance	127 Alignment Improper	386 Lost in Flight
Windshields	7	41.2	31	47.6	7	1	6	1	-	16	-	1	2	3	1	-	-
Corner Glass	32	84.3	13	9.1	1	8	24	-	1	9	-	-	2	-	-	-	-
Roof Windows	71	386.4	29	27.3	11	32	39	-	-	13	1	-	2	1	-	1	-
Pilot/Rescue Door Window	43	173.7	10	27.1	-	20	22	-	-	3	-	-	6	1	-	-	1
Copilot Door Window	28	169.9	9	5.9	-	17	11	2	-	5	-	-	2	-	-	-	-
Side Windows	60	189.6	23	18.2	1	21	39	-	-	11	-	-	10	1	-	-	-
Fuselage Window	11	51.5	2	2.2	-	3	7	1	-	1	-	-	-	-	-	-	1
Cargo Door Window	12	109.5	11	43.9	-	8	4	-	-	1	-	-	10	-	-	-	-
Totals	264	-	128	-	20	110	152	4	1	59	1	1	34	6	1	1	2

Source: Kaman Aircraft, Navy 3M Data System. Flight hours = 22,170



ITEM	DESCRIPTION
1.	ROOF WINDOW K633034-205, K633034-207 — 0.060 IN. ACRYLIC, MIL-P-5425 GREEN R. & H. NO. 2082
2.	CORNER WINDOW K633033-3, K633033-5, K633033-107 — 0.060 IN. ACRYLIC, MIL-P-5425
3.	LOWER SIDE WINDOW K633036-101, K633036-105 — 0.060 IN. ACRYLIC, MIL-P-5425
4.	WINDSHIELD K633035-85, K633035-86 — LAMINATED GLASS, 0.300 IN. THICK (HEATED WINDSHIELD)
5.	FUSELAGE WINDOW K631070-17, 0.060 IN. ACRYLIC, MIL-P-5425
6.	PILOT/RESCUE DOOR WINDOW K633010-17, K633010-101 — 0.060 IN. ACRYLIC, MIL-P-5425
7.	COPILOT DOOR WINDOW K633020-15, 0.060 IN. ACRYLIC, MIL-P-5425
8.	CARGO DOOR WINDOW K633015-15, K631432-59 — 0.060 IN. ACRYLIC, MIL-P-5425

Figure 8. H-2 Transparencies.

TABLE XIX. TH-57* MAINTENANCE ACTION SUMMARY

Item	020 Worn	070 Broken	117 Deteriorated	190 Cracked	230 Dirty	381 Leaking	386 Lost in Flight	605 Crazed	780 Bent Distorted	303 Bird Strike	846 Delaminated	910 Chipped	Totals
	Failure Code												
Windshield (Part Code 11112)	-	2	-	10	3	1	-	2	1	-	-	-	19
Lower Window Assembly (Part Code 11113)	-	11	-	21	1	-	8	-	-	1	-	1	43
Crew Door (Part Code 1111A00)	6	21	-	14	-	1	6	-	-	-	-	-	48
Passenger Door (Part Code 1111B00)	3	6	1	12	-	-	-	-	-	-	-	1	23
Access Door/Window Assembly (Part Code 1113310)	-	2	-	3	1	-	4	-	-	-	1	-	11
Totals	9	42	1	60	5	2	18	2	1	1	2	1	144

Source: Bell Helicopter Company. Total aircraft time = 57, 357 hours. Number of aircraft = 59

*Similar to Army OH-58

TABLE XX. FAILURE CODES (NUMERICAL)

Code	Description
020	Worn excessively (includes deteriorated)
027	Collapsed (includes buckled-warped-bent-sprung)
031	Alignment-improper
070	Broken (includes cracked-cut-torn-punctured)
127	Adjustment-improper
180	Clogged (includes pinched-jammed-seized-locked-binding)
230	Dirty (includes contaminated)
235	Dry
259	Oversize
275	Undersize
381	Leaking (includes seeping)
450	Open
500	Lubrication (includes over-under)
622	Wet
713	Battle damage
717	Accident damage
730	Loose (unstable)
750	Missing
797	No defect-MWO previously complied with
799	No defect (includes component removed and/or reinstalled to facilitate other maintenance-MWO not applicable-partial MWO compliance-removed for scheduled maintenance-removed for time change-removed for troubleshooting)
801	No defect-MWO compliance
900	Burned (includes blistered-corroded-scored-shorted-grounded)
910	Chipped (includes flaking-dented-pitted-grooved-nicked-stripped-frayed)
916	Impending or incipient failure indicated by spectrometric oil analysis
920	Not determined
950	Wrong part

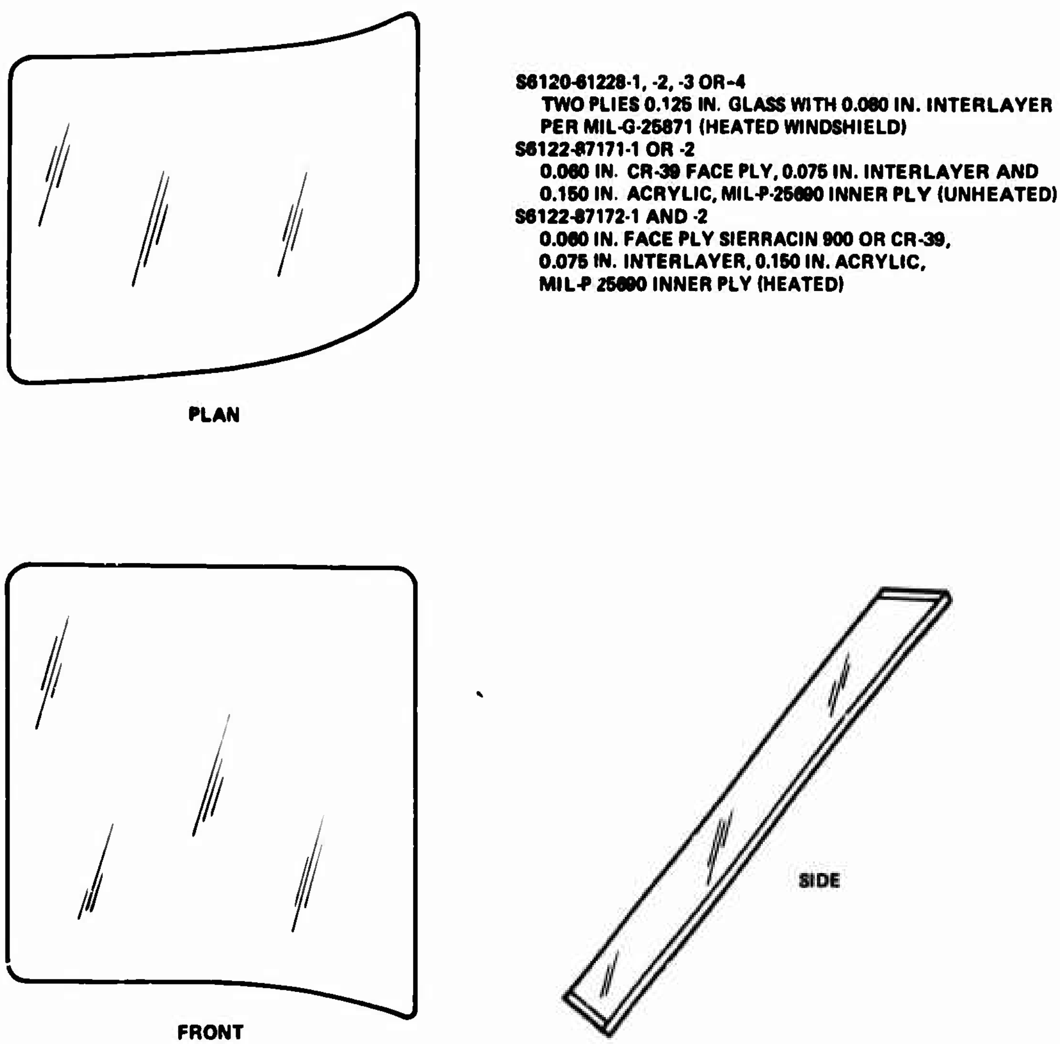


Figure 9. H-3 Windshield Configuration.

"A summary of the problems reported is presented below:

1. Heated laminated glass windshield panels per MIL-G-25871A have been used in all military H-3's and in some commercial S-61's. They are currently in service on all Coast Guard HH-3F's, most Navy SH-3's, and various commercial models. They were originally installed on the first 75 Air Force CH-3C/E's.

   These panels were identified by Sikorsky Specification Control Nos. S6120-61228-1, -2, -3, and -4. They required a step-up transformer with a 416 braided pigtail that had to be spliced to the aircraft wiring. This was extremely troublesome in maintenance because of broken pigtails, inadvertent crossed-phase connections that caused windshield destruction, and inability to maintain waterproof splices. The problems were corrected by adding terminal block connector posts in the -3 and -4 versions.

   The laminated glass panels have been and continue to be exceptionally serviceable and reliable in their present configuration.

2. Unheated stretched Plexiglas 55, Sierracin Corporation coated windshield panels per MIL-P-25690A were introduced in Air Force HH-3E's by retrofit of 17 aircraft in SEA. This was an interim measure to provide the shatterproof quality desired for combat zone operations.

   These units were Sikorsky P/N S6122-87171-1 and -2. Their major deficiency was soon found to be rapid loss of transparency resulting from severe abrasion by grit and dust particles in the areas swept by the windshield wipers. The problem rapidly became critical due to insufficient quantities of spare panels to support the frequent replacements.

   The windshield washer system in use at that time was taken directly from the Navy SH-3 design. It was known to be ineffective in forward flight since it was designed and tested for washing salt from windshields while in a sonar dip hover. It was thought that incorporation of an improved washer system and a 50 percent reduction in wiper speed to be included with the air-to-air refueling modification would, if properly used, increase the windshield coating service life. Subsequent service proved this to be an erroneous assumption. Whether the absence of any apparent improvement could be assigned to improper or nonutilization of the new washer or to a still inadequate water distribution pattern is unknown. The severe, rapid wiper abrasion continued.

3. Heated stretched Plexiglas 55, Sierracin Corporation coated windshield panels per MIL-P-25690 were incorporated in production on the 75th through 133rd (last) Air Force H-3's. The Air Force has since retrofitted these on all but the original 17 HH-3E's (having unheated panels), thus removing the heated laminated glass units from service. The reason for this action was not clear except for the advantage of commonality.

   The heated plastic panels are Sikorsky P/N S6122-87172-1 and -2. Their heating elements are powered by 115 VAC 3-phase with no step-up transformer required. Other than melting some of these plastic panels by neglecting to remove the step-up transformers used with the glass units, no electrical problems have been experienced with the panels themselves. However, the loss of transparency in the wiped areas, just as with the unheated plastic windshields, continues to be a serious problem. The 13 most recently delivered HH-3E's, all assigned to Elmendorf AFB, Alaska, have already reached the point of nonavailability of spare windshield panels due to frequent replacement requirements. Despite this, and the good service experience with the laminated glass, the Air Force has shown no inclination toward reverting to the heated laminated glass units, even in noncombat locations."

PROBLEM AREAS

During the search for specific historical information on specific transparencies, a number of problems were encountered. The Army Maintenance Management System (TAMMS) and the Navy 3M system provide basic forms for recording maintenance actions performed on equipment. These forms (DA Form 2407 for TAMMS) provide for recording the Federal stock number (FSN) of the item repaired or replaced, the failure code, the noun descriptor of the component, the man-hours expended for the maintenance action, and various other information. When it is desired to accumulate the maintenance actions on a specific item, say, the windshield on the CH-47 helicopter, it is accomplished by searching the maintenance records for noun descriptors suggesting anything related to windshields, windows, glass, canopies, etc. Then, for each record where such a noun descriptor appears, the associated desired information such as failure code, FSN, man-hours expended, etc., is printed out in a listing. For the purpose of this study, these listings were then manually searched to identify specific transparencies by their FSN. Unfortunately, many times these listings contained no FSN for a given line of data, so that line had to be discarded even though the noun descriptor may have identified the item as a windshield. Also, for many line items with a listed FSN, the FSN did not agree with any FSN listed for a transparency even though the noun descriptor

again might describe the part as a window or a windshield. Again, that line item would be discarded. This procedure was used for all the AVSCOM maintenance action summaries except that done by Project FG2BWF-04[a] and summarized in Table X. That summary, which was done for a different purpose, did not list FSN's for any of the line items. However, because there are only five transparencies on the AH-1G, and because at least some of the noun descriptors used seem to identify some specific part numbers, it was decided to include the data. Table X illustrates the typical variety of descriptors used to identify transparencies. The point is that many times there seems to be incorrect listing (or omission) of the FSN on the original maintenance request form, thus making it impossible to identify the specific part number responsible for the maintenance action. The question which naturally arises is, "How many valid transparency maintenance actions are being excluded because of errors in preparation of the original DA Form 2407?"

Another serious difficulty was encountered in utilizing the maintenance action surveys for this study. This problem was that the reporting system makes no provisions for accounting for or identifying alternate part configurations with the same FSN. This problem exists for the windshields on the CH-47, where alternate windshield configurations from alternate vendors can be used. The basic windshield part number (and FSN) is the same, but the windshield can be either a laminated glass-plastic configuration or a laminated glass configuration (see Figure 2). Thus, in Table XI it is not possible to determine how many of the maintenance actions for the 114SS604-1 and -2 windshields are for the glass-plastic configuration and how many are for the laminated glass configuration, thereby making impossible a direct comparison of the relative reliability of the two windshields. A similar problem exists for data obtained from the Navy 3M system, which makes no provision for specifically identifying alternate vendor configurations.

DATA ANALYSIS

General

Within the known limitations of the data as previously discussed, the tabular data in Tables IX through XIX were subjected to a critical engineering review and analysis to attempt to define the major failure modes and relate them to helicopter types, transparency type, location, or other parameters which may become apparent during the review.

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[a]This was a maintenance action summary prepared by Director for Management Information Systems, U.S. Army AVSCOM.

For the first step in this review, all the failures listed under failure codes which were not attributable to design faults or characteristics of the transparency itself were eliminated. Failure codes such as 230 (dirty), 713 (battle damage), 717 (accident damage), 730 (loose), 750 (missing), 135 (binding), 381 (leaking), 105 (loose hardware), 386 (lost in flight), 246 (faulty maintenance), and 170 (corroded) were deleted.

Some of the failures could be attributable to faulty design practices for the frames or transparency installation details. For example, the window panels in the fuselage side walls of some helicopters are retained by a rubber extrusion around the perimeter of the window. Many times these windows are lost because they are accidentally pushed out by troop cargo packs when personnel lean back in their seats. Also, leakage problems around windows and windshields are frequently encountered. However, the transparency itself cannot be faulted for these problems because in all likelihood the same problems would exist if an aluminum panel were substituted for the transparency and it was installed in the same manner. These problems will be discussed later.

Overall Analysis

Using the basic data from Tables IX through XIX, an overall summary table was prepared and is presented as Table XXI. This table shows the calendar time period covered by each data survey, the length of the period in months, and the flight hours of the aircraft surveyed during that particular survey period. The approximate fleet size at the time of the survey is also shown where known.

The number of different transparencies encountered during each survey is also included in this table to provide a quick indication of how many transparencies the indicated failures are distributed over. The total failures listed for each survey period and each aircraft are shown in one column. The adjacent column labeled Total Failures (Adjusted) reflects the deletion of those failures not attributable to the transparency, such as battle damage and accident damage as previously discussed. The next two columns show the mean time between failures (MTBF) based on the flight hours shown divided by either the total failures or the adjusted failures. These two columns then indicate the mean time between failures requiring maintenance action of some type and considers all the transparencies on each helicopter. For example, the mean time between transparency maintenance actions on the AH-1 helicopter is 407 hours, when all causes are considered. If causes not related to the characteristics or peculiar requirements of the transparencies are not considered, the mean time between maintenance actions increases to 555 hours.

Table XXI also shows similar data for windshield failures only. For example, the UH-1D windshield MTBF is 749 hours for all failures considered and 906 hours on a relevant (adjusted) failure basis. A report by AVSCOM (Special Study - UH-1D Windshield Replacement Repair, dated 12 October 1972) states that the average installed flight hours between windshield replacements for all repair echelons was 495 flight hours. The AVSCOM study was based on a sample of 170 aircraft, while the study reported herein started with a 40-aircraft fleet and ended with a fleet size of 8 aircraft. The AVSCOM survey did not include flight hours accrued after the last replacement or the flight hours on aircraft which had no replacements. The UH-1 survey reported in Table XXI included the total flight hours on the aircraft fleet surveyed. It is not possible to estimate the number of flight hours dropped from the AVSCOM survey for aircraft with no replacements and hours after the last replacement, but for a 170-aircraft fleet size, the number of hours could be substantial. The net effect if these hours were included would be to increase the number of hours between replacements. Thus, it is seen that the two independent studies give approximately the same failure rates when the differences in data surveys are accounted for.

The last column in Table XXI shows the percent of the total (adjusted) failures accounted for by windshield failures. The percent of windshield failures is seen to have a wide spread - it varies from 0 for the AH-1G to 94 percent for one survey of the CH-47. For the AH-1G, the windshield is defined as the long, narrow cabin center window only (see Figure 1).

AH-1 Helicopter

All the transparencies on this aircraft are made of stretched acrylic 0. 150 inch thick. Originally, all the transparencies were tinted blue. However, all the blue-tinted transparencies are being replaced with clear transparencies because of general complaints about the reduction in visibility due to the blue tint (see text of report).

Table XXII shows the failure data from Table IX adjusted to delete the nonrelevant failures, and the number of failures of each transparency for each failure code and the percentage those failures are of the total (adjusted) transparency failures for the AH-1 helicopter.

Table XXII surprisingly shows the highest failure rates to be in the fixed gunner and pilot windows instead of in the movable door windows. Man-hours to replace the pilot and gunner windows averaged about 25. 5 hours. Unfortunately, the transparency descriptors used in Table X are too broad to permit positive identification of the individual transparencies. However, since the total flight hours are known for this survey, an overall MTBF can be calculated for the transparencies. This MTBF is 555 hours (see Table XXI).

TABLE XXI. HELICOPTER TRANSPARENCY FAILURE SUMMARY

Aircraft	Time Period	Number of Months	Flight Hours	Approximate Fleet Size Surveyed	Number of Transparencies (Line Items)	Data Source	Reference Table	Total Failures Listed	Total Failures (Adjusted)	MTBF (All Failures) (hr)	MTBF (Adjusted) (hr)	Total Windshield Only Failures	Windshield Adjusted Failures	Windshield MTBF (All Failures) (hr)	Windshield MTBF (Adjusted) (hr)	Windshield Failures (Adjusted Total Failures (Adjusted) (pct)
AH-1	July 1970 to December 1970	6	Unknown	-	5	AVSCOM (RAMMIT)	IX	41	29	-	-	0	0	-	-	0
AH-1	Unknown	6	95,476	619	7	AVSCOM Maintenance Action Summary	X	234	172	40	555	Unknown	Unknown	-	-	-
CH-47	July 197[illegible] to June 1971	12	Unknown	187	6	AVSCOM (RAMMIT)	XI	127	126	-	-	93	93	-	-	73.9
CH-47	July 1965 to February 1967	20	[illegible]	-	3	TBC	XII	56	19	122	360	Unknown	Unknown	-	-	-
CH-47	July 1967 to April 1968	10	1,7[illegible].5	-	2	TBC	XII	4	3	466	595	3	2	596	894	66.6
CH-47	April 1968 to June 1969	15	4,974.8	-	3	TBC	XII	22	17	226	293	17	16	293	311	94.1
CH-47	June 1969 to September 1970	15	4,132.2	-	6	TBC	XII	65	14	64	295	27	13	153	319	93
CH-54	July 1970 to June 1971	12	Unknown	48	4	AVSCOM (RAMMIT)	XIII	12	10	-	-	3	3	-	-	30
CH-54	Unknown	Unknown	48,000	-	11	Sikorsky (Contracted Study)	XIV	38	35	1262	1370	9	6 (Laminated Glass) 3 (Acrylic Center Window)	5340	5000	25.7
UH-1	January 1964 to December 1968	60 -	77,085 (1D) 35,731 (1C)	40 -	8 -	Bell Helicopter M and R Program	XV	374 -	268 -	301 -	420 -	103 (1D) 65 (1C)	85 (1D) 63 (1C)	749 549	906 566	55.3
OH-58	January 1970 to June 1971	18	Unknown	293	5	AVSCOM (RAMMIT)	XVI	56	44	-	-	17	11	-	-	25
TH-57	Unknown	Unknown	57,357	59	5	Bell Helicopter (Navy 3M)	XIX	144	119	398	487	19	15	2492	3823	12.6
CH-53	April 1970 to December 1971	21	52,154	-	12	Sikorsky (Navy 3M)	XVII	254	238	206	219	201	200	260	261	84
H-2	January 1971 to December 1971	12	22,170	-	8	Kaman (Navy 3M)	XVIII	392	271	57	82	38	11	553	2010	4.1
								1819	1365							

TABLE XXII. AH-1 TRANSPARENCY FAILURES (ADJUSTED)												
	Failure Code											
	020		027		070		190		910		Total	
Item	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Pilot Window	-	-	-	-	6	20.7	-	-	4	13.8	10	34.5
Gunner Window	-	-	1	3.5	9	31.0	-	-	4	13.8	14	48.3
Gunner Door Window	1	3.5	-	-	2	6.9	-	-	1	3.5	4	13.8
Pilot Door Window	-	-	-	-	-	-	1	3.5	-	-	1	3.5
Cabin Center Window	-	-	-	-	-	-	-	-	-	-	-	-
	1	3.5	1	3.5	17	58.6	1	3.5	9	31.1	29	100.0

CH-47 Helicopter

The crown windows and nose bubbles are cast acrylic per MIL-P-5425, 0.125-inch and 0.150-inch thick, respectively. Early cabin windows were also the same material, 0.080 inch thick. However, these are being changed to stretched acrylic windows of the same thickness. Early windshields were laminated plastic with an inner cast acrylic 0.150-inch-thick inner ply per MIL-P-8184. Later versions are alternate configurations which can be either two plies of 6/64-inch plate glass with an interlayer, or a laminated glass-plastic configuration. The center or intermediate windshield is the laminated plastic configuration. All windshields are electrically heated by means of a conductive coating.

The adjusted transparency failures from Tables XI and XII are shown in Table XXIII. Windshield failures are seen to account for a substantial percentage of the transparency failures. Nearly 40 percent of the failures are attributed to the 114SS604 windshield. Unfortunately, the record system provides no way to identify which failures were in the laminated glass windshield and which were in the laminated glass-plastic windshield. From Table XXI we see that the windshield MTBF is about 310 hours. The July 1967 to April 1968 survey indicates a much higher MTBF, but it should probably be discounted because of the small sample size. The failure rates of the laminated plastic windshields and the laminated glass-faced windshields are almost identical, with MTBF's of 311 and 318 hours, respectively. For the survey periods starting in April 1968 and June 1969, the primary failure mode is scratches. The survey starting in July 1970 shows chipping as the primary failure mode and no scratching failures.

CH-54 Helicopter

The transparencies in the pilot and copilot areas and crane operator area are shown in Figures 3 and 4, respectively. All transparencies are acrylic per MIL-P-8184 or MIL-P-25690, except the pilot and copilot windshields, which are made of two plies of glass with an 0.080-inch interlayer per MIL-G-25871.

Table XXIV shows the adjusted failure data with the nonrelevant failures of Table XIV deleted. The windshields account for approximately 26 percent of the total failures. However, based on 48,000 flight hours, the windshield MTBF is 5340 hours (see Table XXI), the highest number by far for any of the helicopters studied. The highest failure rate is in the door windows, which account for 60 percent of the total failures recorded. These windows fail primarily by cracking, presumably due to repeated door closings or sticking and binding of the sliding windows.

UH-1 Helicopter

The UH-1 helicopter is the one most frequently found in the Army inventory. A variety of material thicknesses are used in the windshields of the various models, but the material in all cases is cast acrylic per MIL-P-8184 except for a few test models which have 0.250-inch stretched acrylic per MIL-P-25690. The UH-1A has a windshield thickness of 0.150 or 0.187 inch. The UH-1B has 0.187- or 0.250-inch material. The UH-1C has 0.250-inch material and the UH-1D has 0.187-inch material.

The transparency failure distribution for the UH-1D is shown in Table XXV for data from Table XX. Over 41 percent of the relevant failures are for the windshield, with the primary failure mode being scratches. This agrees with the

TABLE XXIII. CH-47 TRANSPARENCY FAILURE DISTRIBUTION (ADJUSTED)

Item		Number of Months Covered	Flight Hours	020 Worn Num-ber	020 Worn Per-cent	050 Blistered Num-ber	050 Blistered Per-cent	068 Heater Inoperative Num-ber	068 Heater Inoperative Per-cent	070 Broken Num-ber	070 Broken Per-cent	190 Cracked Num-ber	190 Cracked Per-cent	196 Shorted Num-ber	196 Shorted Per-cent	490 Scratched Num-ber	490 Scratched Per-cent	607 Distorted Num-ber	607 Distorted Per-cent	846 Separated Num-ber	846 Separated Per-cent	900 Burned Num-ber	900 Burned Per-cent	910 Chipped Num-ber	910 Chipped Per-cent	920 Not Determined Num-ber	920 Not Determined Per-cent	935 Scored Num-ber	935 Scored Per-cent	Total Num-ber	Total Per-cent
Window and Windshield Assemblies (except 114S1607-103, -104 and 114S1647-3, -4)	July 1965 to February 1967	20	6837	-	-	-	-	-	-	-	-	7	4.2	-	-	12	7.2	-	-	-	-	-	-	-	-	-	-	-	-	19	11.5
Windshield 114SS601-7, -8	July 1967 to April 1968	10	1788.5	-	-	-	-	-	-	1	0.6	1	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1.2
Crown Pane Assembly 114S714-2	July 1967 to April 1968	10	1788.5	-	-	-	-	-	-	-	-	1	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.6
Windshield, 114SS601-7, -8	April 1968 June 1969	15	4974.8	-	-	-	-	1	0.6	-	-	3	-	1	0.6	6	-	-	-	2	1.2	-	-	-	-	-	-	-	-	13	7.8
Windshield, Intermediate 114SS602-4	April 1968 to June 1969	15	4974.8	-	-	-	-	1	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.6
Crown Pane Assembly 114S1714-30	April 1968 to June 1969	15	4974.8	-	-	-	-	-	-	-	-	1	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.6
Windshield 114SS604-1, -2	June 1969 to September 1970	15	4132.2	-	-	-	-	-	-	-	-	-	-	-	-	8	4.2	2	1.2	1	0.6	-	-	-	-	-	-	-	-	11	6.6
Windshield, Intermediate 114SS602-4	June 1969 to September 1970	15	4132.2	-	-	-	-	1	0.6	-	-	-	-	-	-	-	-	-	-	1	0.6	-	-	-	-	-	-	-	-	2	1.2
Pane Assembly, Nose Bubble 114S1715-35, -36	June 1969 to September 1970	15	4132.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.6	-	-	-	-	-	-	-	-	1	0.6
Windshield 114SS604-1, 2	July 1970 to June 1971	12	Unknown	4	2.4	1	0.6	-	-	15	9.0	5	3.0	-	-	-	-	-	-	-	-	13	7.8	21	12.7	2	1.2	3	1.8	64	38.6
Windshield, Intermediate 114SS602-4	July 1970 to June 1971	12	Unknown	1	0.6	-	-	-	-	15	9.0	2	1.2	-	-	-	-	1	0.6	1	0.6	5	3.0	4	2.4	1	0.6	-	-	30	18.1
Nose Bubble 114S1715-35, -36	July 1970 to June 1971	12	Unknown	-	-	-	-	-	-	6	3.6	-	-	-	-	-	-	-	-	-	-	-	-	2	1.2	-	-	-	-	8	4.8
Crown Pane 114S1714-29, -30	July 1970 to June 1971	12	Unknown	-	-	-	-	-	-	8	-	2	-	-	-	-	-	-	-	-	-	1	-	1	0.6	1	0.6	-	-	13	7.8
				5	3.0	1	0.6	3	1.8	45	27.2	22	13.3	1	0.6	25	15.7	3	1.8	6	3.6	19	11.5	28	17.0	4	2.4	3	1.8	166	100.0

TABLE XXIV. CH-54 TRANSPARENCY FAILURE DISTRIBUTION (ADJUSTED)

	Failure Code											
	190 Cracked		070 Broken		607 Distorted		854 Hazy		520 Pitted		Total	
Item	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Windshield, LH												
6420-61356-101	4	11.4	-	-	-	-	-	-	2	5.7	6	17.1
Windshield, Center												
6420-61328-101	1	2.9	-	-	-	-	-	-	-	-	1	2.9
-102	2	5.7	-	-	-	-	-	-	-	-	2	5.7
Cockpit Canopy Windshield Installation												
6420-61332-101	1	2.9	-	-	-	-	-	-	-	-	1	2.9
-103	-	-	1	2.9	1	2.9	-	-	-	-	2	5.7
Rear Enclosure Installation												
6420-61705-101	1	2.9	-	-	-	-	1	2.9	-	-	2	5.7
Door Window, RH												
6420-61145-226	3	8.6	-	-	-	-	-	-	-	-	3	8.6
Door Window, LH												
6420-61145-170	2	5.7	-	-	-	-	-	-	-	-	2	5.7
-223	7	20.0	1	2.9	-	-	-	-	-	-	8	22.9
-224	7	20.0	1	2.9	-	-	-	-	-	-	8	22.9
Totals	28	80.0	3	8.7	1	2.9	1	2.9	2	5.7	35	100.0

TABLE XXV. UH-1D TRANSPARENCY FAILURE DISTRIBUTION (ADJUSTED)

	Failure Code							
	070 or 190 Broken or Cracked		490 Scratched		841 Abraded		Totals	
Item	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Windshield 204-030-666-31 -32	6	2.9	79	38.5	-	-	85	41.5
Lower Forward Window 204-030-657-19 -20	49	23.9	-	-	-	-	49	23.9
Cabin Window 204-031-669-7	9	4.4	-	-	-	-	9	4.4
Panel Window 204-030-285-1 -2	3	1.5	-	-	-	-	3	1.5
Forward Door Window 204-030-459-1 -2	4	2.0	-	-	-	-	4	2.0
Door Window 204-030-790-1	46	22.4	-	-	4	2.0	50	24.4
Upper Window, Door 204-030-770-1 -2	5	2.4	-	-	-	-	5	2.4
Totals	122	59.5	79	38.5	4	2.0	205	100.0

interview data, which showed a high number of complaints about windshield wiper induced scratches for this model. The broken or cracked failures for the windshield were only 6 out of the total 85 failures. The other high failure rate transparencies were the lower forward (chin) windows and the window in the crew access door. Failure rate of each of these transparencies was about 25 percent, with almost all failures due to breakage or cracks. The failure ates on the other cabin windows were in the range of 2 to 4 percent.

The calculated MTBF for relevant transparency failures is 420 hours for the total failures shown in Table XV. The windshield MTBF's are 906 hours and 566 hours for the UH-1D and UH-1C windshields, respectively.

OH-58 Helicopter

The OH-58 transparencies are all made from stretched acrylic per MIL-P-25690, except for the skylight window, which is polycarbonate. Transparency thicknesses and configurations are shown in Figure 6.

Tables XXVI and XXVII show the relevant transparency failures for the OH-58 and the similar Navy TH-57. The data in Table XXVII are subject to some questions with respect to the last three tabulated items. The data as obtained from the records listed the failures for the total door assemblies and not just the transparencies. In adjusting the data to eliminate the nonrelevant failures, some judgment was necessary in attempting to decide if a particular failure code applied to a transparency or to some other portion of the door. In case of doubt, the failure was assigned to the transparency. Therefore, if some failures are assigned to the transparencies that do not really belong to them, the effect is to show a lower MTBF when all failures are considered. It would also tend to result in a lower overall ratio between the windshield and total failures. Nevertheless, the failure distributions in Tables XXVI and XXVII show reasonable agreement, and it is concluded that the assigned failures are reasonable.

The highest failure rate is in the lower (chin) window, with almost all the failures being broken or cracked failures. It should also be noted that this transparency was the only one with damage reported specifically because of a bird strike (failure code 303). This transparency at 0.060 inch-thick is one of the thinnest used for a forward-facing transparency. In essentially identical commercial versions of this helicopter, this lower window is 0.080-inch-thick stretched Plexiglas 55.

The adjusted MTBF for the windshield is in excess of 3800 hours (Table XXI) based on the TH-57 data. The effect of the differences in operating and mission requirements between the Navy version and the Army version cannot be estimated.

TABLE XXVI. OH-58 TRANSPARENCY FAILURE DISTRIBUTION (ADJUSTED)

	Failure Code											
	020		027		070		190		540		Total	
Item	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Windshield 206-032-115-15 -16	1	2.3	-	-	6	13.6	3	6.8	1	2.3	11	25.0
Crew Door Window 206-032-500-19 -20	-	-	-	-	10	22.8	-	-	-	-	10	22.8
Passenger Door Window 206-032-501-19 -20	-	-	-	-	5	11.4	4	9.1	-	-	9	20.4
Lower Window 206-032-116-15 -16	-	-	1	2.3	13	29.6	-	-	-	-	14	31.8
Skylight 206-031-108-19 -20 -25 -26	-	-	-	-	-	-	-	-	-	-	-	-
Totals	1	2.3	1	2.3	34	77.4	7	15.9	1	2.3	44	100.0

TABLE XXVII. TH-57 TRANSPARENCY FAILURE DISTRIBUTION (ADJUSTED)

Item	Failure Code 020		070		117		190		303		605		780		846		910		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Windshield	-	-	2	1.7	-	-	10	8.4	-	-	2	1.7	1	0.8	-	-	-	-	15	12.6
Lower Window	-	-	11	9.2	-	-	21	17.6	1	0.8	-	-	-	-	-	-	1	0.8	34	28.6
Crew Door	6	5.0	21	17.6	-	-	14	11.8	-	-	-	-	-	-	-	-	-	-	41	34.4
Passenger Door	3	2.5	6	5.0	1	0.8	12	10.1	-	-	-	-	-	-	1	0.8	-	-	23	19.3
Access Door/ Window Assembly	-	-	2	1.7	-	-	3	2.5	-	-	-	-	-	-	1	0.8	-	-	6	5.0
Totals	9	7.5	42	35.3	1	0.8	60	50.4	1	0.8	2	1.7	1	0.8	2	1.6	1	0.8	119	100.0

CH-53 Helicopter

The CH-53 helicopter is not in the Army inventory. However, since transparency survey data are available, it will be reviewed here to provide further field experience applicable to the general helicopter transparency reliability problem.

Figure 7 shows the general transparency configurations, locations, and materials. The relevant failure codes from Table XVII are recompiled in Table XXVII to show the failure rates by transparency and failure code. The combined failure rates for the three windshields (left hand, right hand, and center) account for 83. 8 percent of the total relevant failures. The most frequent windshield failures listed are: delaminated, 33. 5 percent; crazed, 20. 6 percent; and scarred, 14. 2 percent.

The calculated MTBF for all relevant transparency failures is 206 hours, and the MTBF for the windshields only is 261 hours (see Table XXI).

H-2 Helicopter

The Kaman H-2 helicopter is not in the Army inventory, but the field service data available for it provides additional background reliability data for helicopter transparencies.

The relevant failure distributions are shown in Table XXIX for the transparencies as defined in Figure 8. Table XXIX shows that the windshield accounts for only 4. 1 percent of the relevant transparency failures. The highest failure rate is in the roof window, which accounts for 27 percent of the recorded failures. The failure mode for almost all these failures is broken or cracked. The lower side window and the corner window in the cockpit area account for 22. 5 percent and 12. 2 percent of the failures, respectively. Again, the primary failure mode is cracked or broken.

The overall transparency MTBF for relevant failure is a very low 82 hours. The windshield MTBF, however, is 2010 hours for relevant failures. The reason for the very low overall MTBF is the large number of broken or cracked corner, roof, copilot door, and side windows as shown in Table XXIX.

MISCELLANEOUS

Another important criterion which requires consideration in any investigation of helicopter transparency maintenance actions is the number of man-hours required for performance of the action. In reviewing listings of the maintenance actions, wide variations in man-hours will be observed for identical operations. This was reported also in the AVSCOM special study of the UH-1D windshield. Because

TABLE XXVIII. CH-53 TRANSPARENCY FAILURE DISTRIBUTION (ADJUSTED)

Item	Failure Code																Total	
	070		117		190		607		846		900		935		Crazed			
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Windshield, LH 65206-01003-109	2	0.8	-	-	4	1.7	1	0.4	23	9.6	-	-	14	5.9	20	8.4	64	26.9
Windshield, RH 65206-01003-110	1	0.4	-	0.4	10	4.2	5	2.1	21	8.8	1	0.4	12	5.0	14	5.9	65	27.2
Windshield, Center 65206-01009-105	1	0.4	-	-	4	1.7	5	2.1	36	15.1	2	0.8	8	3.3	15	6.3	71	29.7
Overhead Window, LH 65206-01004-101	1	0.4	-	-	-	-	2	0.8	-	-	-	-	1	0.4	1	0.4	5	2.1
Lower Glass, RH 65206-01006-102	-	-	-	-	-	-	-	-	-	-	-	-	1	0.4	-	-	1	0.4
Bottom Glass, LH 65206-01007-101	1	0.4	-	-	1	0.4	1	0.4	-	-	-	-	1	0.4	-	-	4	1.7
Bottom Glass, RH 65206-01007-102	-	-	-	-	-	-	-	-	-	-	-	-	1	0.4	-	-	1	0.4
Cabin Windows 65206-05003	7	2.9	1	0.4	6	2.5	1	0.4	-	-	-	-	-	-	-	-	15	6.3
Personnel Door Window 65207-03035-081	1	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.4
Forward Cabin Escape Window 65207-03039-081	3	1.3	-	-	1	0.4	-	-	-	-	-	-	-	-	-	-	4	1.7
Window, Rear Door 65207-10028-041	4	1.7	-	-	2	0.8	1	0.4	-	-	-	-	-	-	-	-	7	2.9
Totals	21	8.7	2	0.8	28	11.7	16	6.7	80	33.5	3	1.2	38	15.9	50	20.9	238	100.0

TABLE XXIX. H-2 TRANSPARENCY FAILURE DISTRIBUTION (ADJUSTED)

Item	Failure Code 020		070		116		117		190		520		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Windshield K633035-85 -86	3	1.1	1	0.4	-	-	-	-	6	2.2	1	0.4	11	4.1
Corner Window K633033-3 -5 -107	-	-	8	3.0	-	-	1	0.4	24	8.9	-	-	33	12.2
Roof Window K633034-205 -207	1	0.4	32	11.8	1	0.4	-	-	39	14.4	-	-	73	27.0
Copilot Door Window K633020-15	-	-	17	6.3	-	-	-	-	11	4.0	-	-	28	10.3
Side Windows K633036-101 -105	1	0.4	21	7.7	-	-	-	-	39	14.4	-	-	61	22.5
Fuselage Windows K631070-17	-	-	3	1.1	-	-	-	-	7	2.6	-	-	10	3.7
Cargo Door Windows K633015-15 K631432-59	-	-	8	3.0	-	-	-	-	4	1.5	-	-	12	4.5
Totals	6	2.3	110	40.7	1	0.4	1	0.4	152	56.1	1	0.4	271	100.0

all maintenance echelons are covered by the data surveys, a rather wide variation in experience levels will exist, and the wide variations in man-hours will result No attempt was made herein to modify any of the raw data by dropping any excessively low or high values. The data presented in Tables IX through XVIII represent a simple summation of all the man-hours reported for the maintenance actions listed. The average replacement man-hours were then calculated from this and are included in Table XXX.

Table XXX shows a summary of transparency failure data. The three transparencies most frequently failing for each helicopter are listed in the first column. The second column shows the number of relevant failures covered by the survey for that helicopter, and the third column shows what percentage that number of failures is of the total number of relevant transparency failures recorded for that helicopter. The next three columns show the three top failure codes followed by the percentage of those transparency failures attributable to that failure code. For reference purposes, the basic transparency material and thickness are shown in the next column.

The column titled Average Monthly Demand has been prepared from information furnished by the Materials Management Organization at AVSCOM. This number represents an average of the number of requests received for each transparency. The replacement requests are from worldwide operations of the entire Army fleet. The averages were calculated from requests received over either a 12- or a 24-month period. In those cases where two separate transparencies are considered, such as the pilot or copilot windshields, the average monthly demand as shown in Table XXX is the summation of the average demands of the two windshields.

The next column in the table shows the average failures per month as indicated from the maintenance action surveys. This was calculated by dividing the number of failures listed in the first column by the number of months covered by the survey for that helicopter. The last column in the table is the average man-hours required to replace that particular transparency.

The first six columns of Table XXX are self-explanatory and require no further discussion. However, some comment is required on the average monthly demand and the average failures per month columns. For surveys which cover the entire helicopter fleet of a given model, these two columns should be nearly the same if the averages were made over the same calendar time period. The replacement demand should equal the number of failures. Comparison of the two columns, however, shows no correlation; the demand is many times the replacement rate. Some of this discrepancy can probably be attributed to stockpiling the transparencies at the various maintenance echelons. Another explanation may be

TABLE XXX. TRANSPARENCY FAILURE SUMMARY

Item	Number of Failures	Percent of Total Failures	Top Three Failure Codes and Percent of That Total Transparency Involved: Code	Percent	Code	Percent	Code	Percent	Construction	Average Monthly Demand	Average Failures per Month	Average Replacement Man-Hours
AH-1												
Gunner Window	14	48.3	070	64.3	910	28.6	027	7.2	0.150 acrylic, MIL-P-25690	7.3	2.34	21.9
Pilot Window	10	34.5	070	60	910	40			0.150 acrylic, MIL-P-25690	4.8	1.67	31.1
Gunner Door Window	4	13.8	070	50	910	25	020	25	0.150 acrylic, MIL-P-25690	7.5	0.67	15.1
		96.6										
CH-47												
Windshield, Pilot or Copilot	64	55.6	910	32.8	070	23.4	900	20.3	0.085-inch glass face interlayer, acrylic	60.5	5.34	2.36
Windshield, Intermediate	30	26.1	070	50.0	900	16.7	910	13.3	or two 5/64-inch glass plies and interlayer Sierracin 900 face ply, interlayer, acrylic	24.2	2.50	3.5
Crown Pane	13	11.3	070	61.5	190	15.4	900	7.7	0.125-inch acrylic, MIL-P-5425	29.2	1.08	8.5
		93.0										
CH-54												
Side Cockpit Door Window (P/N 6420-61145-223 or -224	16	45.7	190	87.5	070	12.5	-	-	0.125-inch acrylic, MIL-P-25690	Unknown	Unknown	Unknown
Windshield (P/N 6420-61356-101)	6	17.2	190	66.7	520	33.3	-	-	Two plies 0.125-inch glass and interlayer	Unknown	Unknown	Unknown
Windshield, Center	3	8.6	190	100	-	-	-	-	0.100-inch acrylic, MIL-P-25690 or MIL-P-8184	Unknown	Unknown	7.3
		71.5										
UH-1D												
Windshield	85	41.5	490	93	070	7	-	-	0.187-inch acrylic, MIL-P-8184	104.7	Unknown	11.8
Door Window	50	24.4	070	92	841	8	-	-		156.1	Unknown	
Lower Forward Window	49	23.9	070	100	-	-	-	-	0.125-inch acrylic, MIL-P-8184	96.6		
		89.8										
OH-58												
Lower Window	14	31.8	070	93	027	7	0	0	0.060-inch acrylic, MIL-P-25690	-	0.78	11.7
Windshield	11	25.0	070	54.5	190	27.3	020	9.1	0.100-inch acrylic, MIL-P-25690	8.5	0.61	35.2
Crew Door Window	10	22.8	070	100	-	-	-	-	0.080-inch acrylic, MIL-P-25690	9.4	0.56	12.8
		79.6										
CH-53												
Windshield, Pilot or Copilot	129	52.6	846	34.1	Crazed	26.4	935	20.2	Sierracin 900 or CR-39, interlayer and	Unknown	6.15	Unknown
Windshield, Center	71	29.0	846	50.7	Crazed	21.1	935	11.3	acrylic inner ply/MIL-P-25690	Unknown	5.90	Unknown
Cabin Windows	22	8.0	070	31.8	386	31.8	190	[illegible].3	0.080-inch acrylic, MIL-P-8184	Unknown	1.83	Unknown
		90.5										
H-2												
Roof Window	73	27	190	53.5	070	43.9	020	1.4	0.060-inch acrylic, MIL-P-5425	Unknown	6.09	5.4
Lower Side Windows	61	22.5	190	64.0	070	34.5	020	1.6	0.060-inch acrylic, MIL-P-5425	Unknown	5.08	3.2
Corner Window	33	12.2	190	72.8	070	24.2	117	3.0	0.060-inch acrylic, MIL-P-5425	Unknown	2.75	2.6
		61.7										

that the average monthly demand data also includes repeat requests for transparencies due to shortages or slow delivery. Such explanations are based on conjecture, however, and the final judgment of the validity of the data is left to the reader.

A brief review of the transparency replacement man-hours is also in order here. Table XXX shows considerable variation in average times required for replacement. The shortest replacement times are shown for the laminated windshields on the CH-47. This is because the holes are predrilled on the laminated panels instead of being drilled at installation, as is common with monolithic acrylic transparencies. For the monolithic transparencies, the installation time is related to the transparency size (edge perimeter), primarily since the number of fasteners is approximately proportional to the perimeter.

SUMMARY AND CONCLUSIONS

The following general conclusions can be drawn from the previous analyses:

1. When considering the transparency relevant failures, the six most frequent failure modes and their approximate frequency of occurrence are: broken, 35.6 percent; cracked, 24.1 percent; scratched, 10.5 percent; delaminated, 8.7 percent; and crazed, 5.1 percent.

2. Use of windshield wipers on plastic surfaces results in a high percentage of scratched or scored failure modes (reference UH-1, CH-53, CH-47, and H-3 helicopters).

3. For laminated, heated windshields, the MTBF for relevant failures is about 300 hours (reference CH-47 and CH-53 helicopters). The major failure modes for the heated, laminated windshields are: delaminated, 27 percent; crazed, 15 percent; scored, 12 percent; broken, 11 percent; cracked, 9 percent; and chipped, 8 percent.

4. Laminated glass windshields have significantly longer life cycles than laminated plastic windshields. The CH-54 laminated glass unheated windshield at 8000 hours has the highest MTBF for all the helicopters surveyed for which field service data was available. The H-2 helicopter heated, laminated glass windshield MTBF is 2010 hours. The primary failure mode for the heated H-2 windshield is cracking with 55 percent of the relevant windshield failures. The unheated CH-54 windshield also shows cracking as the primary failure mode, accounting for 67 percent of the windshield failures.

5. Monolithic acrylic windshields have high MTBF's if windshield wipers are not used. The TH-57 (OH-58) windshield MTBF is 3823 hours and the CH-54 acrylic center window MTBF is 16,000 hours.

6. Acrylic windows in hinged doors such as the pilot and copilot doors and cabin doors have a high incidence of failures due to being cracked and broken. No clear trend is indicated relative to the durability of one type of acrylic material versus another for this application.

7. Cabin windows mounted with molded or extruded rubber glazing gaskets around their periphery are frequently accidently pushed out or lost in flight.

APPENDIX II
MILITARY AND COMMERCIAL DOCUMENTS

APPLICABLE MILITARY SPECIFICATIONS AND DOCUMENTS

Military Standards and Specifications

1. MIL-P-25690, Plastics, Sheets and Parts, Modified Acrylic Base, Monolithic, Crack Propagation Resistant
2. MIL-P-8184, Plastic Sheet, Acrylic, Modified
3. MIL-P-5425, Plastic, Sheet Acrylic, Heat Resistant
4. MIL-G-25667, Glass, Monolithic, Aircraft Glazing
5. MIL-P-8257, Plastic Sheet, Thermosetting, Transparent
6. MIL-P-6997, Plastic, Working and Installation of Transparent Sheet, General Specification
7. MIL-P-8576, Adhesive, Acrylic Base, For Acrylic Plastic
8. MIL-T-5842, Transparent Areas, Anti-Icing, Defrosting and Defogging Systems, General Specifications For
9. MIL-P-25374, Plastic Sheet, Acrylic, Modified, Laminated
10. MIL-P-83310, Plastic Sheet, Polycarbonate, Transparent
11. MIL-STD-850B, Aircrew Station Vision Requirements for Military Aircraft
12. MIL-HDBK-700 (MR), Military Standardization Handbook, Plastics
13. MIL-STD-1241, Optical Terms and Definition
14. MIL-HDBK-80-1, Handbook of Instructions for Airplane Designers
15. MIL-HDBK-17, Part II - Plastics for Flight Vehicles
16. MIL-I-18259, Installation of Window Anti-Icing, De-Greasing, and Washing Systems (General Specification For)

17. MIL-STD-1241A, Military Standard Optical Terms and Definitions

18. MIL-G-25871, Glass, Laminated, Aircraft Glazing

19. MIL-STD-810, Environmental Test Methods

Air Force Systems Command

1. Design Handbook 2-2, Section 2A - Crew Accommodations, Design, Note 2A17, Helicopters, dated 1 November 1970

2. Design Handbook 2-1, Section 3A Substructures, Design Note 3A1 - Transparencies

3. Abstract - Air Force Materials Symposium, Transparent Materials Sessions 4G and 5G, 21 May 1970, AFML.

APPLICABLE COMMERCIAL SPECIFICATIONS AND DOCUMENTS

Bell Helicopter Company

1. Specification No. 299-947-090, Procurement Specification for Plastics Sheet, Acrylic, Heat Resistant, Rev. D, dated 22 February 1971.

2. Special Acceptance Standard No. 3023, Optical and Contour Acceptance Criteria for 206 Transparent Enclosures, Rev A.

3. 34:DAR:ab-1300, Optical Acceptance Standard for Blown Acrylic Helicopter Enclosure Components, dated 22 November 1965, Bell Helicopter Company - Quality Department.

4. Special Acceptance Standard No. 3000, Acceptance Criteria for Plexiglass Panels, part no. 204-030-657-19 and -20, dated 26 January 1965.

Boeing Vertol Division

1. D8-0660, General requirements for electrically heated laminated panels for CH-47 helicopters, no date.

2. 114-AF-001, Qualification Test Procedure Glass-Faced Laminated Electrically Heated Windshields, Rev. B, dated 4 October 1966.

3. D8-0005:02.0280, Functional Test Procedure, Electrically Heated Windshield, Rev. C, dated 16 July 1971.

4. D210-10337-1, Procurement Specification for Formed Transparent Glass-Faced Laminated Electrically Heated Windshield Panel, dated 5 November 1971.

5. PS-432, General Requirements for Electrically Heated Plastic Panels to be Used in the Windshields of the YHC-1B and HC-1B, Rev. D, dated 12 April 1961.

6. PS-488, General Requirements for Electrically Heated Plastic Panels for Windshields of the HRB-1, Rev. A, dated 26 September 1961.

Hughes Tool Co. - Aircraft Division

1. HP 30-68, Inspection and Test - Optical Distortion of Helicopter Canopy, Rev. B, dated 25 January 1968.

2. HP-30-69, Inspection and Test - Optical Distortion of Helicopter Canopy Glass Fabricated from Cast Acrylic Sheet, dated 6 November 1969.

3. HP-30-70, Inspection and Test - Optical Distortion of Helicopter Door Glazing Fabricated from Cast Acrylic Sheet, dated 29 July 1970.

4. HMS 16-1805A, Polycarbonate, Press Polished Sheets for Canopy and Windows, Rev. A, dated 2 May 1972.

Kaman Aircraft Corporation

1. Kaman Engineering Specification 1158, Detail Specification for HU2K-1 Helicopter Application Electrically Heated Windshield; Electrical, Optical and Structural Requirements For, Rev. C, dated 24 February 1959.

PPG Industries, Incorporated

1. Acceptance Test Procedure No. 1691 for CH-47A, B, C Transport Helicopter Windshields, P/N 114SS605-1 and -2, dated 30 January 1970.

FAA

1. Part 27, Airworthiness Standards: Normal Category Rotorcraft.

2. Part 29, Airworthiness Standards: Transport Category Rotorcraft.

3. Advisory Circular No. 29.773-1; Subject: Pilot Compartment View, dated 19 January 1966.

APPENDIX III
MODEL HELICOPTER TRANSPARENCY SPECIFICATION

SCOPE

This specification contains the requirements for transparencies for use on Army helicopters. The requirements and design objectives specified herein have been developed based on the mission requirements of Army helicopters and evaluation of maintenance records of existing in-service helicopters.

APPLICABLE DOCUMENTS

The following specifications and publications of the issue in effect on date of invitation for bids, form a part of this specification to the extent specified herein:

Document Number	Title
MIL-P-5425	Plastic, Sheet, Acrylic, Heat Resistant
MIL-P-6886	Plastic, Sheet, Acrylic
MIL-P-7524	Plastic, Sheet, Acrylic Laminated, Heat Resistant
MIL-P-8184	Plastic, Acrylic Sheet, Modified
MIL-P-5952	Plastic Areas, Transparent, Aircraft, Optical Inspection of
MIL-P-25374	Plastic Sheet, Acrylic, Modified, Laminated
MIL-G-25667A	Glass, Monolithic, Aircraft Glazing
MIL-G-25871	Glass, Laminated, Aircraft Glazing
MIL-P-25690	Plastic, Sheets, and Parts, Modified Acrylic Base, Monolithic, Crack Propagation Resistant
MIL-STD-850B	Aircrew Station Vision Requirements for Military Aircraft
MS 33575	Dimensions, Basic, Cockpit, Helicopter

REQUIREMENTS

General Requirements

Vision requirements for the aircrew station shall be as specified in MIL-STD-850. The number, location, size, shape, and other physical parameters of the transparencies required to comply with the vision requirements of MIL-STD-850 will largely be a function of the overall helicopter configuration. Use of compound curved transparencies shall be kept to a minimum to minimize distortion.

For nonprecipitation conditions the following apply:

1. Each pilot compartment must be arranged to give the pilots a sufficiently extensive, clear, and undistorted view for safe operation.

2. Each pilot compartment must be free of glare and reflection that could interfere with the pilots' view. If night operation is required, this requirement must be met during night flight.

For precipitation conditions, each pilot must have a sufficiently extensive view for safe operation:

1. In heavy rain at speeds up to the maximum horizontal speed of the aircraft

2. In the most severe icing condition specified by the procuring agency.

Transparency Classification*

All transparencies shall be divided into classes based primarily on their location and use in the helicopter. Classes shall be as shown in Table XXXI.

Transparency Construction

Transparencies in Classes A through E can be either monolithic or laminated construction. The type of construction used for any specific transparency will depend upon the transparency location and specific helicopter mission requirements.

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*Contains concepts that are new or have had inadequate considerations on helicopter transparency applications.

TABLE XXXI. TRANSPARENCY CLASSIFICATION	
Class	**Description**
A	All windshields and transparencies viewed through by pilot or copilot for forward vision during flight. For side-by-side seating, center panels between pilot and copilot shall also be placed in this class.
B	Chin or lower bubble transparencies generally located forward of the crew but below the horizontal line of forward vision. Used primarily during landing maneuvers
C	Side transparencies primarily used for lateral vision by the pilot or copilot
D	Eyebrow transparencies located above the pilot or copilot head level to provide overhead vision
E	Transparencies located in the fuselage cargo areas to provide illumination to the compartment

It is not the intent of this specification to dictate the type of construction used for each transparency classification. However, certain requirements or combinations of requirements may dictate not only the type of construction but also the type of material used, i.e., glass, plastic, or a combination of glass and plastic. The type of decision tree that must be utilized for present state-of-the-art materials is shown in Figure 10.

DETAIL REQUIREMENTS

Rain Removal Methods*

Rain removal for Class A transparencies may be specified by the procuring agency or it may be necessary to meet the helicopter mission requirements. If windshield wipers are used for rain removal, the surfaces in contact with the wipers shall be inorganic glass or have protective coating which will add sufficient abrasion resistance to allow windshield wiper use on plastic surfaces.

*Contains concepts that are new or have had inadequate considerations on helicopter transparency applications.

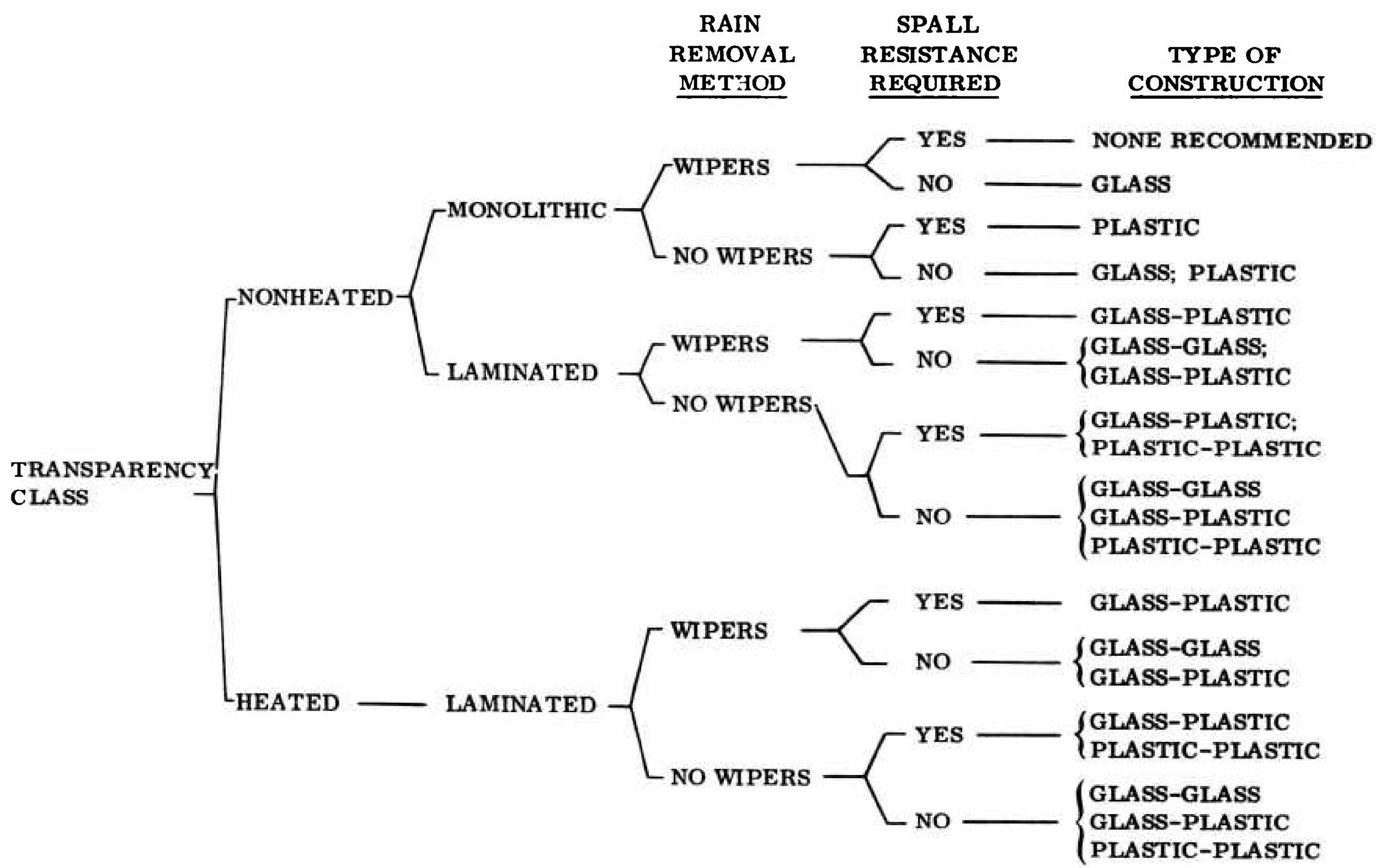

Figure 10. Typical Decision Tree.

Defogging/Deicing

Deicing and/or defogging of Class A transparencies shall be accomplished if specified by the procurement agency or if necessary to meet the mission requirements. The systems shall be designed in accordance with the requirements of MIL-T-5842. If an electrically conductive coating is used to meet these requirements, the transparency shall be of laminated construction and the conductive coating shall be applied to one of the interior surfaces of the laminate.

Ballistic Properties

When specified by the same procurement agency, the transparencies in the crew area shall be spall resistant. Spall resistance shall be determined in accordance with the requirements of the paragraph headed Spalling and Visibility Through Damaged Panels.

For Class A transparencies, the crack pattern in the critical vision area of the panel shall permit sufficient visibility to allow emergency flight and landing of the aircraft after a bullet strike.

For Class A transparencies, the fracture pattern after a bullet strike shall not be so extensive that complete panel integrity is lost and large portions of the panel break off from flight loads.

Crashworthiness/Safety

The transparency fracture characteristics shall be such that in the event of a crash, no sharp splinters, jagged pieces, or projectiles are generated which would present an undue additional hazard to the crew members or passengers. This section shall apply to all transparencies so located either that they could be struck by crew members or passengers in a survivable crash or that portions of broken transparency could be propelled toward areas occupied by passengers or crew. Nonsplintering safety glass shall be used in glass windshields or windows.

Fail-Safe Construction

No material or type of construction shall be used for a Class A transparency whose failure as a result of foreign object damage or other cause would result in complete loss of forward visibility for the pilot. Neither shall a material or type of construction be used whose fracture would cause complete loss of more than 25 percent of the panel area. If complete loss of 25 percent of the panel area would significantly affect the helicopter controllability or expose the pilot to excessive aerodynamic forces or adverse environmental conditions,

then the percentage of allowable total panel loss shall be reduced to a level approved by the procuring agency.

Structural Requirements

All transparencies shall be capable of withstanding the aerodynamic, vibration, and other structural loads induced during normal operation. For transparencies installed in hinged or sliding doors, particular attention shall be paid to integrated transparency, edge attachment, and door frame design so that the resulting assembly has adequate strength and rigidity to withstand repeated opening and closing cycles.

Environmental Requirements

High and Low Temperature

All transparencies shall be capable of normal operation when exposed to temperatures from -65°F to +160°F.

Thermal Shock

All transparencies shall be capable of withstanding thermal shock in accordance with anticipated limits as indicated by the aircraft flight envelope. All transparencies will be tested in accordance with the paragraph entitled Flight Test Evaluation. Transparencies with electrically conductive coatings for deicing/defogging must meet the requirements of the paragraph entitled Thermal Shock Test.

Moisture

All transparencies shall be capable of normal operation during and after exposure to 100 percent relative humidity and rainfall up to ____ inches per hour. Electrically heated glazings shall meet the requirements of the paragraph entitled Moisture, described under Qualification Tests.

Vibration

All transparencies shall be capable of normal operation during exposure to the vibration environment as shown in MIL-STD-810B, Method 514. The procuring agency will specify the procedure to be used.

Optics

The transparency optical test methods and requirements shall be in accordance with the paragraph entitled Optical Tests. Detail optical test methods and requirements are as follows:

1. Minor Optical Defects - These defects shall be in accordance with paragraph heading Optical Tests, Item 2.

2. Critical Vision Area Minor Optical Defects - Such defects shall be in accordance with the paragraph entitled Optical Tests, Item 3.

3. Noncritical Vision and Other Area Minor Optical Defects - These defects shall be in accordance with the paragraph entitled Optical Tests, Item 4.

4. Optical Distortion - The optical distortion of the transparency shall meet the requirements specified in the paragraph entitled Optical Tests, Item 5.

5. Luminous Transmittance and Haze - The luminous transmittance and haze of the transparency shall be in accordance with the paragraph entitled Optical Tests, Item 7.

Heat Transfer Characteristics

The required heat transfer characteristics of the transparencies depend upon their location in the helicopter, the type of transparency construction, and the helicopter mission requirements. No specific heat transfer properties are required except that they shall be known with sufficient accuracy so that heat transfer studies made in conjunction with design of heated transparencies or design of cabin airconditioning systems can be performed within the required accuracy requirements.

Reflection Coatings

Flight Station Reflections

To the extent possible, the flight station transparency configurations and locations shall be evaluated with respect to undesirable reflections and glare during cockpit and interior lighting mock-up reviews. Presence of undesirable and/or hazardous reflections in the Class A transparencies which cannot be reduced or eliminated by changes in the location or positioning of the transparency shall be cause for the addition of an antireflective coating to the transparency interior or interior and exterior surfaces.

External Reflections

Unless otherwise specified, low-reflective coatings shall not be applied to the transparencies to reduce external reflections or flash from the transparencies.

Radar Reflective Coating

Unless otherwise specified, a radar-reflective coating shall not be required. When radar reflectance is specified, transparencies with an electrically conductive coating for heating purposes will normally exhibit satisfactory reflectance if the conductive coating resistivity is 15 ohms per square or less. Satisfactory reflectance may also be exhibited with higher resistivities depending upon the transparency construction and the viewing angle. A radar reflectivity survey should be performed or the performance of questionable heated transparencies evaluated before an additional radar-reflective coating is applied.

Radar-reflective coatings, when required, shall be selected to provide maximum adhesion to the applied surface and maximum durability and abrasion resistance.

Abrasion Resistance

The transparency shall be made of materials capable of resisting abrasive damage in the service environment. Testing for abrasion resistance shall be waived for all transparencies having inorganic glass outer surfaces. All windshield panels having outer surfaces of materials other than inorganic glass, which are designed for use with windshield wipers, shall be tested in accordance with the paragraph entitled Windshield Wiper Abrasion Test. All other transparency materials shall be tested for abrasion resistance in accordance with paragraph entitled General Abrasion Resistance Test. The procuring agency shall specify the minimum number of test cycles that each transparency material shall withstand which results in a 5-percent haze value increase.

Chemical Resistance

The transparency shall be made of materials having suitable resistance to chemicals anticipated in the service environment.

Weight

Transparency weight shall be the minimum practical weight consistent with overall requirements as specified herein.

Birdproofing

Class A transparencies as normally designed exhibit adequate bird resistance for the infrequent encounters and velocities experienced in helicopter operations. Unless otherwise specified, specific birdproof qualification shall not be required.

Fire Resistance

Materials used for construction of transparencies shall be classified as non-burning or slow burning.

Static Discharge

Unless otherwise specified by the procuring agency, antistatic coating of the transparency shall not be required.

MAINTAINABILITY

Ease of Maintenance

Requirements for special equipment or maintenance procedures for maintenance of the transparencies shall be minimized. Recommended repair techniques shall be provided for each transparency configuration. Materials and repair procedures to be used shall be specified. Maximum damage limitations such as crack length, depth, and location or delamination area, and location, scratches, crazing, etc., shall be specified for each transparency so that reparable and nonreparable damage can be readily identified.

Reliability

The requirements identified in this specification were selected to result in the design of an optimum transparency with respect to functional requirements. Transparency reliability should result in a design made in accordance with these guidelines. Additional requirements may be required to assure reliability of new designs for helicopter transparencies. These additional requirements should be specified by the procurement agency or may be suggested by the transparency designer or manufacturer for incorporation in the specification.

Installation and Removal Techniques*

The transparency shall be designed so that installation and removal can be accomplished with the minimum man-hours and minimum time out of service. The following guidelines shall be followed for design of the transparency to simplify installation and removal procedures.

*Contains concepts that are new or have had inadequate considerations on helicopter transparency applications.

1. No attachment holes are permitted through glass.

2. Use of rivets to attach transparencies should be avoided; bolt attachment into nut plates is preferable.

3. Spacers, collars, or shoulders should be used to prevent excessive tightening against the transparency.

4. Provisions shall be made to prevent excessive stresses due to relative distortions between the transparency and the frame from thermal expansion or deflections due to structural loads.

LIFE-CYCLE COSTS

The objective of this specification is to specify only those requirements necessary to ensure design of an optimum transparency with respect to its particular functional requirements. If any changes in requirements as specified herein would result in development of a significantly lower cost transparency without seriously degrading the overall transparency functional requirements, such changes shall be called to the attention of the procuring agency for possible consideration.

QUALITY ASSURANCE PROVISIONS

Qualification Tests

General

Qualification testing is required on each new design and should include as a minimum the following tests. The type and number of test articles as well as the identification of acceptable test agencies shall be agreed upon by the procuring agency and the supplier. Tests applicable only to laminated or laminated heated glazings are identified by underlined test headings. Test parameters which are considered to be a function of specific designs cannot be specified in this document and are left blank.

All qualification testing will be accomplished only after completion of the production acceptance tests outlined in the paragraph entitled Acceptance Tests for each panel used in qualification testing.

Moisture

The moisture test shall be accomplished prior to all other qualification tests required herein. The panel shall be tested for its ability to withstand moisture in the following manner:

1. Water - Tap water shall be run continuously over the panel for periods of two to eight hours without benefit of a water (rain) removal system. (Rainfall may be substituted for this procedure provided periods and intensity of rainfall exist that would simulate the conditions outlined.) Immediately following the above procedure, the panel shall have the heating medium energized with operating voltage for one hour to determine if the windshield functions properly. Any failure or condition that is detrimental to the operation of the panel anti-ice and anti-fog capabilities shall be cause for rejection. This test shall be repeated once per week for a period of six weeks.

2. High Humidity - The panel shall be mounted in a dummy frame to simulate aircraft installation, and the complete unit placed in a test chamber for a period of 14 days. During this period, the test chamber shall be maintained at a temperature of $120^{o}F$ and at a minimum of 95 percent relative humidity. At the end of the period, the panel shall be removed from the test chamber and inspected for delaminations. Immediately after the panel has cooled to an ambient temperature of $75^{o}F$, $\pm 5^{o}F$, the heating medium shall be energized with temperature-controlled operating voltage for a period of one hour. The panel shall again be inspected for delamination. Any evidence of delamination shall be cause for rejection.

Temperature Cycling Test

A life temperature cycling test shall be conducted on the panel while mounted in a dummy frame and placed in a test chamber. The test chamber shall be maintained at a temperature of __^{o}F (___^{o}C) or lower, during which time 2,000 complete heating cycles shall be conducted on the panel. A windshield panel temperature controller shall be used to control the power to the panel to bring the temperature of the heating medium up to __^{o}F from an ambient temperature of __^{o}F. A complete heating cycle is defined as starting from ambient temperature (__^{o}F), up to the controlling temperature (___^{o}F), and returning to ambient temperature (__^{o}F). A cycle

counter and an indicating lamp shall be installed on the test rig to record the number of cycles to which the panel is subjected. Any evidence of delamination, cracking, or other detrimental effects resulting during the test shall be cause for rejection.

Flight Test Evaluation

Three test windshield panels shall be provided for installation on aircraft for the purpose of flight evaluation. The flight evaluation shall subject the panels to exposure to environmental vibration and weathering conditions.

1. Flight Test Profile - Normal mission profile will be flown by the helicopters. The panel design shall be considered satisfactory for this requirement if 300 flight hours have been accumulated, of which at least 20 hours have been spent in the hovering mode, and with the windshield temperature controller ON. Visible degradation of the panel structure shall be cause for rejection.

2. Rapid Descent - A rapid descent test shall be conducted five consecutive times from an altitude of 10,000 feet above sea level to 1,000 feet above terrain. The helicopter shall dwell at 10,000 feet for a period of 15 minutes prior to each descent. Evidence of delamination of the panel shall be cause for rejection.

Vibration Testing

The ability of the panel to withstand vibrations encountered in helicopter operation will be established during the Flight Test Evaluation tests outlined in the above paragraphs. Satisfactory completion of the 300 hours of flight noted in the paragraph entitled Flight Test Profile shall constitute fulfillment of the vibration test requirement of this paragraph.

Structural Deflection

The panel shall be mounted in a test fixture similar to the helicopter production panel support frame. A uniform design ultimate pressure of approximately ____ psi shall then be applied to the outside panel surface and the resulting deflection measured at several places including geometric center of the inside surface. The outside pressure shall then be increased in increments not exceeding 0.2 psi to provide a pressure deflection plot up to the panel failure.

Abrasion Resistance*

1. Windshield Wiper Abrasion Test - This test is required only for helicopters outfitted with windshield wipers and windshield panels having outer surfaces of materials other than inorganic glass. The test shall be conducted to determine the windshield's ability to withstand wiper abrasion. The tests shall be conducted as follows:

   a. The windshield or a test sample of the windshield material shall be mounted in framework simulating flight attitude of the aircraft.

   b. A windshield wiper shall be mounted to the framework. The rubber blade used shall duplicate that used on the aircraft. The blade will be operated at ____ strokes per minute with a blade pressure to the windshield surface of ____ to ____ lb/in. of blade length.

   c. A moderate flow of tap water shall be run over the windshield continuously during the test to simulate rain.

   d. A test shall be conducted for _____ cycles (equivalent to 5 percent utilization of the wiper at high speed for a 1,000-hour duty cycle).

   e. At the conclusion of the _____ cycles, there shall be no marks or scratches present that would limit the use of the windshield during flight operations.

2. General Abrasion Resistance Test - This test is required for all transparencies having outer surfaces of materials other than inorganic glass, and which are not subjected to windshield wiper abrasion. The test method represents a technique developed to more closely simulate the actual abrading environment and was documented in Technical Report AFML-TR-72-117. (NOTE: This is a tentative procedure which utilizes an abrader that provides a larger test area on a sample than Tabor equipment. The larger test area completely covers the light orifice of the hazemeter and consequently allows more quantitative measurements (reference Method 3022, Federal Test Standard 406).

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*Contains concepts that are new or have had inadequate considerations on helicopter transparency applications.

3. Scope - This method is designed for use in determining the resistance of plastic surfaces to abrasion. Controlled abrasion is accomplished with the use of a Goodyear Aerospace A71QS337 abrader. Testing is accomplished with a hazemeter as specified in Method 3022 of Federal Test Standard 406.

4. Test Specimens - Dimensions - The specimen shall be a rectangular plate 8 inches by 4 inches.

5. Apparatus - A Goodyear Aerospace A71QS337 abrader or equivalent shall be used for sample preparation. A Gardner Pivotable-Sphere Hazemeter or equivalent shall be used for testing.

6. Materials - Pad material, flocked neoprene rubber 0.060 inch thick hardness Shore A, 65 durometer on flocked side; abrasive film, aluminum oxide lapping film, 12-micron grit; lubricant, water.

7. Procedure -

   a. Preliminary Data - Measure and record the light transmission and haze for each test sample.

   b. Load - Prepare the number of abrading shoes for an equivalent number of samples. Weigh the abrading arm and shoes (minimum of two shoes). Divide the weight by the shoe contact area of 8 square inches per shoe. Add weight to the abrading arm until the shoe pressure average is 1 $\pm$0.5 psi. Mount the specimens and the abrading arm.

   c. Abrasion - Abrasion will be performed wet. The surfaces of the samples are to be kept continually wet with distilled water periodically being applied with a squeeze bottle and spout.

   d. Speed - The cycle counter is to be zeroed and the speed set for 20 cycles/minute. The machine is then started.

   e. Duration - The test is to be stopped at the completion of every 1,000 cycles. The samples are to be washed free of chips and abrasive with distilled water and air-dried.

The samples may then be tested for light transmission and haze. At each 1,000-cycle point, the abrasive film will be changed. Testing is terminated when a 5 percent increase in haze has been reached and the total number of cycles is recorded.

8. Report - The report shall include:

   a. Material being tested

   b. Number of samples

   c. Coating being tested (if applicable)

   d. Average load in psi

   e. Pad material

   f. Speed in cycles/minute

   g. Abrasive size

   h. Abrasive type

   i. Lubricant

   j. Light transmission and haze measurements before the test and every 1,000 cycles thereafter

   k. Total number of cycles to 5 percent haze increase

   l. Appearance after the test.

Spalling and Visibility Through Damaged Panels*

Testing for spalling and visibility through damaged panels shall be included only if so specified by the procuring agency. Testing shall be conducted as follows:

The panel shall be mounted in a dummy support frame to simulate helicopter installation. The test fixture shall be mounted so that the panel is installed at an angle of ____ from the horizontal. Two .30-caliber armor-piercing or ball rounds shall be fired at each panel and shall impact the outer face at _____ obliquity. The resultant spalling, if it does not penetrate an aviator's

*Contains concepts that are new or have had inadequate considerations on helicopter transparency applications.

helmet visor material when it is placed as a witness plate and at a distance commensurate with that between the pilot and the panel, is acceptable. Additionally, the resulting crack pattern in the critical vision area which results from projectile impact on the panel shall permit sufficient visibility to allow the pilot to perform successful emergency flight and landing of the helicopter. (NOTE: The area of the windshield between the critical vision area boundary and the edge shall not be considered in determining visibility.)

Acceptance Tests

The acceptance tests shall be performed on each panel to assure that quality and performance provisions of the specification are met. Acceptance tests applicable only to laminated heated types are identified by underlining the test headings.

Dimensions and Contour

Each panel shall be examined and inspected for compliance with the dimensional and contour requirements as specified on specification control drawing ______________. Deviation from dimensional or contour requirements specified thereon shall be cause for rejection.

Optical Tests

1. General - Each panel shall be examined, inspected, or tested for optical defects as specified below.

2. Minor Optical Defects - Minor optical defects as determined by visual examination in the equivalent of light from a clean sky, without sun, shall be permitted only to the extent specified below. Minor optical defects are defined as inclusions in the panel such as:

    a. Seeds, bubbles, small cullet, and dust or dirt particles up to 3/32-inch in diameter

    b. Fine striae, cord, thin traces of crayon, and fingerprints

    c. Light surface scratches and fine lint or hair up to 3 inches in length.

3. **Critical Vision Area Minor Optical Defects** - Minor optical defects shall not be permitted in any critical vision area designated by the procuring activity when:

   a. They are so grouped as to form an objectionable pattern or obscure vision.

   b. Any defect has a maximum dimension exceeding the limits of the paragraph entitled Minor Optical Defects.

   c. The total number for the applicable panel size and thickness exceeds the additive total permitted by specifications MIL-P-5425, MIL-P-8184, MIL-P-25690, MIL-G-25667, MIL-P-25374, or MIL-P-83310 for the individual glass or plastic plies plus the allowable number specified in Table XXXII for each interlayer.

TABLE XXXII. ALLOWABLE MINOR DEFECTS IN EACH INTERLAYER

Area of Daylight Opening (sq ft)	Maximum Number of Minor Defects Per 0.120 Inch or Fraction Thereof in Interlayer Thickness
0.00 through 4.00	4
4.01 through 6.00	6
6.01 through 8.00	9
8.01 through 10.00	12
10.01 through 15.00	19
15.01 through 20.00	26
Over 20.00	As specified

4. Noncritical Vision and Other Area Minor Optical Defects - Minor optical defects in a noncritical vision area shall be disregarded provided they neither form an objectional pattern nor are so grouped as to impair visibility. Light surface sleeks, light plastic rubs or streaks, and blemishes smaller than the minimum stated dimensions in any area shall also be disregarded provided that they do not form an objectionable pattern nor are grouped so as to impair visibility. The presence of vents, stones or vee-edge chips in any area shall be cause for rejection. The area of the panel covered by the mounting frame and extending 1/4 inch inboard may include any defect except vents, stones, vee-edge chips and blowing exceeding 1/4 inch deep and 1 inch long. Unless otherwise specified by the contract or order, noncritical areas shall be considered as a border extending 2 inches from the edge of the daylight opening.

5. Optical Distortion - Optical distortion of all types of transparencies shall be determined by a test based on the principle of viewing a grid through the transparency and measuring the optical distortion by direct measurement, measurement of a photograph, split-line determination, or by visual comparison with agreed upon reference samples. Grid tests of a photographic type shall be made in accordance with the following procedure.

6. Photographic Grid Test Procedure - A grid board preferably utilizing a white background and with black horizontal and vertical lines forming a grid with 1-inch squares and a rigidly mounted camera capable of producing double-exposure pictures shall be employed. The camera shall be mounted 15 feet from the grid board with the center of the lens perpendicular to the approximate center of the grid board. Each panel shall be placed at an angle simulating installation in the helicopter, and placed between the camera and the grid board with the center of the panel 5 feet from the camera, and with the exterior (outboard) face of the panel toward the grid board. A double-exposure technique shall be used whereby the panel shall be photographed with the grid board as a background and the panel removed, and the grid board alone shall be photographed on the same negative. The resulting double exposure shall be used to analyze and determine the maximum slope of any distorted grid lines as viewed through the panel.

In the critical area of Class A transparencies, the maximum slope of distorted grid lines shall not exceed 1:12. No limits of linear distortion shall apply in the 2-inch border area around the edge of the daylight opening. In the critical area of Class B through Class E transparencies, the maximum slope of distorted grid lines shall not exceed 1:8.

The presence of opaque or translucent mottled areas in this noncritical area shall be cause for rejection. Bus bars, sensing elements, lead wires, nontransparent edge attachment material, etc., if present, shall not be considered part of the transparent area. In lieu of the foregoing, the supplier may submit an acceptance test procedure subject to approval of the procuring agency.

7. Luminous Transmittance and Haze - Unless otherwise specified, the luminous transmittance and haze of any transparency shall be in accordance with the requirements of the military specifications for the type of material used (MIL-P-5425, MIL-P-8184, MIL-P-25690, MIL-P-25374, MIL-G-25667, MIL-G-6-25871, or MIL-P-83310). If the transparency construction is other than that specified by any of the preceding specifications, the luminous transmittance and haze shall be specified by the procuring agency. For all Class A transparencies, the minimum luminous transmittance shall be not less than 70 percent and the maximum haze shall not exceed 4 percent after accelerated weathering.

Sensing Element

Each panel shall be tested to assure that the temperature-sensing element is capable of withstanding ________ rms a-c volts applied for a period of 1 minute, then cut off momentarily and reapplied until a total of five on-off cycles are achieved. Upon completion of five cycles, the resistance of the sensing element shall be checked for compliance with the resistance value limits specified by the manufacturer. In lieu of the foregoing test procedure, the supplier may submit an acceptance test procedure subject to approval by the contracting agency. Failure of the panel to meet the requirements of this test shall be cause for rejection.

Bus-to-Bus Resistance

The bus-to-bus resistance shall be ________ to ________ ohms when measured at 75°F, ±5°F, with an ohmmeter accurate to 0.05 ohm.

Bus Bar Voltage Drop

When applicable, operating voltage shall be applied bus to bus and the voltage drop on each bus measured between the end of the bus bar at the power lead and the end of the bus bar farthest from the power lead. Voltage drop shall not exceed _______ volts.

Dielectric Strength

Each panel shall be capable of withstanding _______ volts rms, _______ cps without arcing or voltage breakdown for a period of _______ minutes. Flow of current shall not constitute failure if the resistance of the leakage circuit measures _______ ohms or more between:

1. Sensor terminals to metal insert
2. Power terminals to metal insert
3. Power terminals to sensor terminals
4. Power terminals to exterior surface of electrically heated outer glass ply.

Failure of any of the above tests shall be cause for rejection.

Heat Distribution Test

1. General - Each panel shall be tested to assure that it is free of high gradient hot spots (i. e., highly localized and steep temperature gradients produced when operational electrical current flows through the heating medium). This testing shall be accomplished in the sequenced steps outlined as follows.

2. Polarized Light - Each panel shall be surveyed visually with polarized light prior to applying any electrical current to the heating medium so that any minor optical defects that might later be mistaken for hot spots can be identified and recorded.

3. Electrically Energized - Each panel shall be electrically energized for _______ cycles at 50 percent, 100 percent, and 150 percent nominal power, or as specified on the

supplier's acceptance test procedure and approved by the contracting agency. The maximum cycle duration shall not exceed ________ seconds or that time necessary for the temperature of the heating medium to rise to ________ ^{o}F, whichever occurs first. Throughout the energized cycles, the panel shall be surveyed using polarized light and any hot spots shall be recorded. Any delamination, cracking, clouding, etc., which occurs during this test shall be cause for rejection.

Thermal Shock Test

Each panel shall be capable of withstanding full power thermal shock at a temperature of -65^{o}F with no evidence of arcing, distortion, spalling, cracking, or other deleterious effects. The procedure for thermal shock testing the panel shall be as follows:

The panel shall be placed in a cold chamber having an environmental air temperature of -65^{o}F, ±5^{o}F and allowed to soak until the panel temperature has stabilized. Upon temperature stabilization, the panel heating medium shall be energized with design power, and the temperature of the panel shall be allowed to rise to ________ ^{o}F. The heating medium shall have the electrical power shut off manually by means of an external control and the panel permitted to reach a stabilized temperature of -65^{o}F, ±5^{o}F. This shall be repeated for a total of ________ cycles.

Temperature Uniformity

1. General - Each panel shall be tested to assure that the temperature uniformity is within a ±________ ^{o}F tolerance range. The method of determining temperature uniformity shall be as specified on the supplier's acceptance test document as approved by the procuring agency, or as specified below.

2. Electrical Operation - Each panel shall be energized with design power for the time interval necessary to attain operating temperature at the sensing element with ambient room temperature at 75^{o}F, ±5^{o}F. Power, therefore, shall be modulated to permit stabilization of the panel at the design operating temperature. Iron-constantan thermocouples attached to 1-inch-square (or round) by 0.060-inch-thick copper discs shall be placed at regularly spaced points at approximately 3- to 4-inch intervals and on the exterior face of the panel within the heated area. A Wheelco

recorder, or equivalent, shall be used to record the temperature at each thermocouple. Failure of the panel to conform to the requirements of the paragraph entitled Temperature Uniformity shall be cause for rejection.

Electrical Load Balance

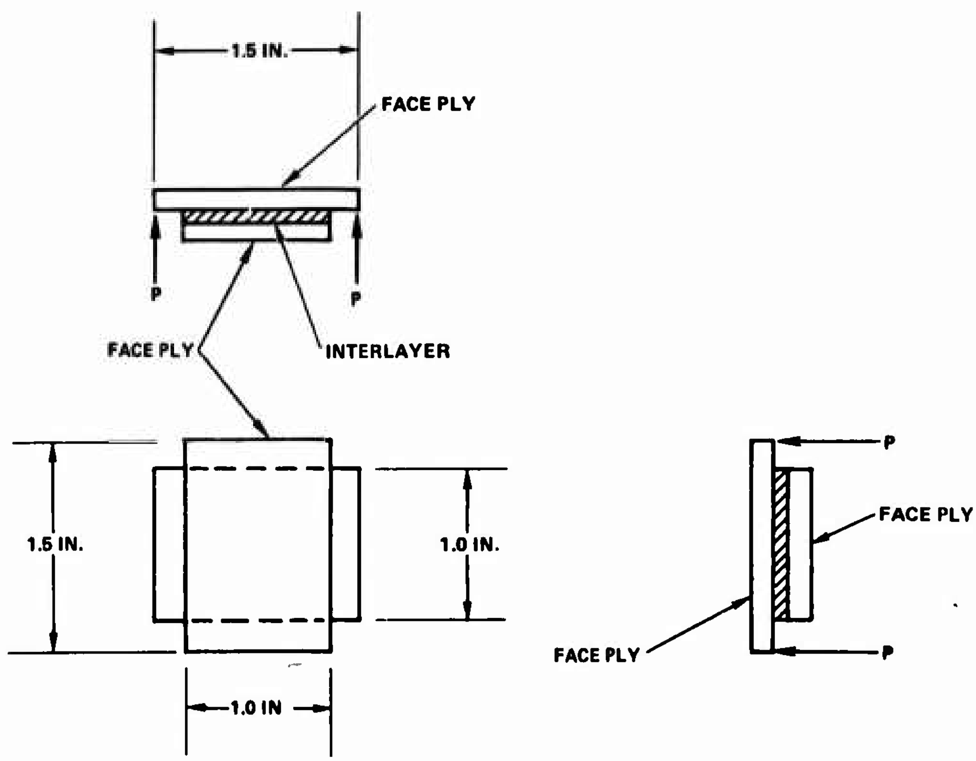
Each panel shall be tested for electrical load balance of the heating medium of each individual area defined on the specification control drawing ______ ____________. The panel shall be tested and the power measured once when operating power is applied to the heating medium with the panel cold-soaked to a stabilized temperature of -65°F, ±5°F, and twice when operating power is applied to the heating medium with the panel stabilized at an ambient room temperature of 75°F, ±5°F. The power loading of the panel shall be balanced within ±_______ percent of the average of the three measured loads. Exceeding this requirement shall be cause for rejection of the panel.

Structural Tests

1. General - The bond shear strength and the bond tensile strength of the laminates of each panel shall be tested as outlined below. The shear and tensile specimens may be taken directly from each windshield panel before final assembly, or the samples may be fabricated and processed parallel to the manufacture of the panel they will represent in the test.

2. Bond Shear Strength - The bond shear strength of the laminates of each panel shall be _______ psi minimum when tested in accordance with Federal Test Method Standard No. 406, Method A of Method No. 1042, and at a specimen test temperature of _______ $^{\circ}$F to _______ $^{\circ}$F and after the specimen has been exposed to a minimum temperature of _______ $^{\circ}$F for a period of not less than _______ hours. In lieu of the foregoing, the supplier may submit an acceptance test procedure subject to approval by the procuring agency.

3. Bond Tensile Strength - The bond tensile strength of the laminates of each panel shall be _______ psi minimum when tested at a loading rate of _______ psi per minute and at a test temperature of _______ $^{\circ}$F to _______ $^{\circ}$F. The tests shall be conducted on bond tensile strength specimens constructed and the loads and reactions applied in accordance with Figure 11 of this specification. In lieu of the foregoing, the supplier may submit an acceptance test procedure subject to approval by the procuring agency.



NOTE:
LOAD P IS TO BE APPLIED SUCH THAT PEELING OF FACE PLIES AND INTERLAYER DOES NOT OCCUR; ADDITIONAL LOAD DISTRIBUTING PLIES MAY BE BONDED TO THE FACE PLIES FOR PURPOSE OF LOADING.

Figure 11. Loads and Reactions.